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Background
Kivalina, Alaska, is a 500-person Iñupiaq community in Northwest Alaska 80 miles north of the Arctic Circle. The people of Kivalina live on the southern tip of a remote, barrier island village. For decades, Kivalina residents have been working to mitigate the impacts of coastal erosion on the barrier island, and to improve community access to fundamental services, including running water and adequate sanitation. The Kivalina Strategic Management Plan (2016) defines access to water and sanitation as among the community's top priorities.[5]

Families in Kivalina, as well as in 29 other unserved villages in Alaska, still live in homes without running water or toilets. Instead of toilets, people use honeybuckets (5-gallon paint cans lined with garbage bags and topped with a toilet-seat lid). No municipal waste collection service exists in Kivalina. Plastic bags of honeybucket waste are staged outside family homes, sometimes for months at a time, until residents volunteer or get paid to dispose of them. Residents self-haul raw domestic waste via a personal or borrowed snowmachine or 4-wheeler to the Kivalina landfill, an open pit, unlined, and unmanaged dump located on a narrow stretch of the eroding barrier island approximately one mile from the village site just north of the airport. The dump does not designate a place for residents to dump the honeybucket bags, so they are scattered everywhere. The footprint of the landfill has exceeded the original design and is now spreading unmanaged from the ocean side to the lagoon side of the island. Without a designated or lined receptacle for the human waste, honeybucket waste is co-mingled with other trash.[6] Increasingly since the early 2000s, ocean storm events erode the coastline at the dump site, causing refuse and human waste to blow over the beach and leach into the Kivalina lagoon.

On February 3, 2015,[7] the Native Village of Kivalina and the City of Kivalina jointly commissioned the Kivalina Biochar Reactor to improve community access to sanitation in a safe and affordable manner. The concept for Kivalina's System emerged from investigations into how new forms of non-sewered, on-site, haul-based sanitation systems benefitting under-served communities in other parts of the world could be adapted to serve remote Alaskan tribal communities lacking access to adequate and affordable sanitation.

The Kivalina Biochar Reactor is North America's first nonsewered and relocatable sanitation system. It refines materials from Urine Diverting Dry Toilets[8] (UDDTs) installed in a growing number of Kivalina homes into a valuable biochar product through pyrolysis. UDDTs are waterless toilets whose ergonomic design separates urine and feces used inside the home to separate solid from liquid wastes. Mechanical ventilation built into the toilet draws air over the waste, partially drying the materials and preventing malodor in the home. UDDT materials have about a 40 percent moisture content when they're removed from the toilet. Kivalina families using UDDTs are emptying their UDDT bags about 1–2 times per week. For comparison, the same families emptied their honeybuckets approximately 2-3 times per day.

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[5] https://www.commerce.alaska.gov/web/Portals/4/pub/1_Kivalina_SMP_September_2016.pdf
[6] *See* Exhibit 4.
[7] *See* Exhibit 5.
[8] The Alaska Native Health Consortium plans to install 50 UDDTs in Kivalina homes by 2020. Currently, there are 7 UDDTs in use in Kivalina, and ANTHC plans to install an additional 23 UDDTs in Kivalina during the summer of 2019, and 22 during the summer of 2020 (personal correspondence with ANTHC (May 13, 2019)).

The pyrolysis process that refines the UDDT materials uses a high-temperature, low-oxygen environment to refine the solids into a pathogen-free carbon product. After pyrolysis, system emissions undergo a thermochemical process by passing through a stainless-steel monolith catalyst coated with platinum and other noble metals. The byproduct biochar is a carbon-rich, pathogen-free, substrate that has demonstrated commercial value as a valuable product. Biochar has been used to filter odor and as a substrate to boost plant growth and remediate pollution at contaminated sites, among other valuable uses.

The System uses wood pellets and cardboard as start-up fuels to obtain the pyrolysis temperatures necessary to render biochar as an output (approximately 600C). Wood pellets are a form of clean cellulosic biomass and meet the definition of a traditional fuel as defined by 40 CFR 241.2. Cardboard was selected as a fuel primarily because, unlike wood pellets, it is abundantly available in Kivalina; materials packed in cardboard shipping containers arrive in Kivalina, a remote village off the road system that is unconnected to the mainland, daily by air and once annual by barge. In addition, cardboard has a high heat value.

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Definitions
The Resource Conservation and Recovery Act (RCRA) defines "solid waste" according to the statutory definition provided by the Solid Waste Disposal Act: ''... any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material … resulting from industrial, commercial, mining, and agricultural operations, and from community activities…." 42 U.S. Code § 6903.

The RCRA definition of "solid waste' turns on the meaning of "discarded." The ordinary, plain English meaning of a "discarded" material is material that is thrown away, disposed of, or abandoned. S*ee American Mining Congress v. EPA*, 824 F.2d 1177 (DC Cir. 1987); *see also* FR 76 15468.

For a solid waste to be considered a hazardous waste under RCRA, it must meet the definition of solid waste under RCRA subtitle C. *See* 40 CFR 261.2. Non-hazardous materials are regulated under RCRA Subtitle D's solid waste program. Under Subtitle D, RCRA considers non-

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[14] *See* Exhibit 6 (tribes are considered "institutions" by the EPA; however, waste is collected from tribal members, as opposed to tribal institutions, leaving an open question as to whether the "institutional" criteria are met by a program collecting household waste from Kivalina's tribal members).
[15] RCRA, Subtitle D (40 CFR Parts 257 and 258).

hazardous secondary materials that are discarded to be a solid waste.[16] Materials determined to be solid wastes that are combusted must be combusted in solid waste incineration units meeting emission standards under section 129 of the CAA.[17] Non-hazardous secondary materials are not considered "solid waste", however, when used as fuels or ingredients in combustion units under RCRA or the CAA.[18] Non-waste materials can be used as fuels or ingredients in boilers, process heaters, or other units subject to emission standards under sections 111 and 112 of the CAA.

As stated in the Federal Register:

> If a non-hazardous secondary material [ ] is not a "solid waste" under RCRA, then a unit combusting that material must be regulated pursuant to CAA Section 112 if it is a source of HAP. Alternatively, if such secondary material is classified as a "solid waste" under RCRA, then a unit combusting that material must be regulated under CAA section 129, unless it is within the scope of one of the exclusions from the definition of "solid waste incineration unit" in section 129(g)(1) of the CAA.[19]

Standards found under 40 CFR 241.3(a) and (b) identify whether or not a non-hazardous secondary material ("NHSM", or "secondary materials") is a solid waste when used as a fuel or ingredient in a combustion unit. Solid human waste from UDDTs is untreated household waste. Household waste is considered a solid waste but not a hazardous waste under 40 CFR 261.4(b)(1): "'Household waste' means any material (including garbage, trash and sanitary wastes in septic tanks) derived from households (including single and multiple residences, hotels and motels, bunkhouses, ranger stations, crew quarters, campgrounds, picnic grounds and day-use recreation areas)."

Non-Waste Fuel Designation

With respect to fuels, a discarded NHSM that is sufficiently processed into a new legitimate fuel product is not a solid waste when combusted. 40 CFR 241.3(b)(4). The processed fuel must meet the definition of "processing" under 40 CFR 241.2 to qualify as a non-waste fuel. Processing is defined by 40 CFR 241.2 as "operations that transform discarded NHSMs into a non-waste fuel or non-waste ingredient, including operations necessary to: remove or destroy contaminants; significantly improve the fuel characteristics, e.g. sizing or drying of the material in combination with other operations; chemically improve the as-fired energy content; or improve the ingredient characteristics." The EPA has found that minimal processing such as shredding to solely reduce the size of the material is not sufficient to constitute "processing" under the definition provided.[20]

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[16] The regulations that pertain to non-hazardous secondary materials define solid waste in five ways that largely mirror the statutory definition of solid waste under RCRA. *See* 40 CFR 240.101(y); 40 CFR 243.101(y); 40 CFR 246.101(bb); 40 CFR 257.2; and 40 CFR 258.2.

[17] If any solid waste is combusted in a combustion unit, a unit is considered a solid waste incineration unit. *See* *NRDC* v. *EPA*, 489 F.3d 1250 (DC Cir. 2007).

[18] *See* 40 C.F.R. part 241.

[19] 76 FR 15461.

[20] *See* EPA "Part 241 Response and Clarification Letters," under "W" (Waste Determinations for Combusted Non-Hazardous Secondary Materials), https://rcrapublic.epa.gov/rcraonline/topics.xhtml#W (accessed June 17, 2019).

After processing, the NHSM fuel must meet the legitimacy criteria in 40 CFR 241.3(d)(1) to be designated as a non-waste fuel. Under these criteria, secondary materials are not considered "solid waste" if they are used as a fuel, handled and managed as a valuable commodity, have a meaningful heating value, and contain contaminants that are not significantly higher in concentration than traditional fuel products.

Finally, the NHSM fuel must also either: remain "within control of the generator,"[21] such that it has not been discarded in the first instance; or, as an alternative in instances where standards for defining "within control of the generator" cannot be met, a petition may be submitted to the Regional Administrator in accordance with 40 CFR 241.3(c) demonstrating that the material, even though it has been transferred to a third party, has not been discarded in the first instance, and meets legitimacy and other relevant criteria in 40 CFR 241.3(c) and (d)(1).

Non-Waste Ingredient Designation

To be designated as a non-waste ingredient, certain legitimacy criteria must be met.[22] NHSM's that constitute ingredients must be handled and managed as a valuable commodity, provide a useful contribution, their recycling must result in a valuable product, and the product must not contain contaminants that are significantly higher in concentration than traditional products.[23]

A NHSM ingredient is considered to be managed as a valuable commodity based on the following factors:[24]

> (A) The storage of the non-hazardous secondary material prior to use must not exceed reasonable time frames;
>
> (B) Where there is an analogous ingredient, the non-hazardous secondary material must be managed in a manner consistent with the analogous ingredient or otherwise be adequately contained to prevent releases to the environment;
>
> (C) If there is no analogous ingredient, the non-hazardous secondary material must be adequately contained to prevent releases to the environment;

A NHSM ingredient provides a useful contribution to the production or manufacturing process if it contributes a valuable ingredient to the product or intermediate or is an effective substitute for a commercial product.[25]

An NHSM ingredient produces a valuable product or intermediate if it is sold to a third party, or if it is used as an effective substitute for a commercial product or as an ingredient or intermediate

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[21] *See* 40 CFR 241.2 ("Within control of the generator means that the non-hazardous secondary material is generated and burned in combustion units at the generating facility; or that such material is generated and burned in combustion units at different facilities, provided the facility combusting the non-hazardous secondary material is controlled by the generator; or both the generating facility and the facility combusting the non-hazardous secondary material are under the control of the same person as defined in this section.")

[22] 40 CFR 241.3(d)(2).

[23] *Id*.

[24] 40 CFR 241.3(d)(2)(i).

[25] 40 CFR 241.3(d)(2)(ii).

in an industrial process.[26]

Finally, a NHSM ingredient must produce products that contain contaminants at levels that are comparable in concentration to or lower than those found in traditional products that are manufactured without the non-hazardous secondary material.[27]

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[26] 40 CFR 241.3(d)(2)(iii).
[27] 40 CFR 241.3 d)(2)(iv).

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TABLE OF EXHIBITS

	Description	Date
1.	Re-Locate/Biomass Controls, Determination Letter to Marcia Mia, Office of Compliance/Air Branch, EPA HQ	[redacted]
2.	EPA R10 Letter to Re-Locate LLC Re: Classification of Kivalina Biochar Unit under Section 129 of the Clean Air Act	[redacted]
3.	Biomass Controls, Kivalina Biochar Reactor Standard Operating Procedure	July 30, 2019
4.	[redacted]	[redacted]
5.	[redacted]	[redacted]
6.	[redacted]	[redacted]
7.	[redacted]	[redacted]
8.	Full Kivalina Biochar Reactor System Diagram	Undated
9.	EPA, Contaminant Concentrations in Traditional Fuels: Tables for Comparison (*see* Table 2 at p. 3)	Nov. 29, 2011
10.	[redacted]	[redacted]
11.	Dovetail Partners, Inc., SURVEY AND ANALYSIS OF THE US BIOCHAR INDUSTRY	Nov. 2018
12.	[redacted]	[redacted]
13.	Bangalore Test House, Pathogen Report to Tide Technocrats Pvt. Ltd. for biochar produced by a similar system in India	July 30, 2015
14.	Alaska Department of Environmental Conservation, Solid Waste Program, Letter of Non-Objection	June 19, 2017
15.	[redacted]	[redacted]
16.	Kivalina Biochar Reactor Request for Letter of Non Objection for DOT lease in Kivalina, E-mail to Jennifer Marlow from Patrick Dunn, Alaska Department of Environmental Conservation Division of Air Quality	July 4, 2017

RE-LOCATE LLC

[redacted]

RE-LOCATE LLC

BIOMASS CONTROLS

August 10, 2017

Marcia B. Mia
Office of Compliance/Air Branch
2227A WJCS
U.S. Environmental Protection Agency

To Marcia Mia:

Please accept this letter as a follow up to our teleconference on July 26, 2017. The contents below are provided in response to your request for more information about the Kivalina Biochar project in order to guide the EPA's determination about whether a federal air quality permit is required.

Kivalina Biogenic Refinery
The Kivalina Biogenic Refinery (the Kivalina Biochar Reactor, or the "System") is a pilot health and sanitation project pursuant to Joint Resolution 15-01 of the City of Kivalina and the Native Village of Kivalina (signed February, 2015, and updated September, 2015). The Kivalina Biogenic Refinery is designed to process solid human waste from Urine Diverting Dry Toilets (UDDTs) and refine the waste into biochar—a carbon-rich, high-energy dense solid.

Overview of the System
The Kivalina Biogenic Refinery is a compact, community-scale, relocatable human solid waste refinery designed and built by Re-Locate LLC in partnership with Biomass Controls, LLC. The System processes solid human waste via pyrolysis (combustion in a low-oxygen

environment) from UDDTs installed in Kivalina homes and outputs inert, pathogen-free biochar along with thermal energy in the form of heat. The pyrolysis system is sized to eventually accommodate human solid waste from Kivalina's population of approximately 500 residents, although only 8–10 families are using UDDTs at the present time. The System is rated to process 400 pounds per day of daily biogenic waste. The thermal rating of the System is 175,000 BTUs, a thermal output that is less than many residential heating systems.

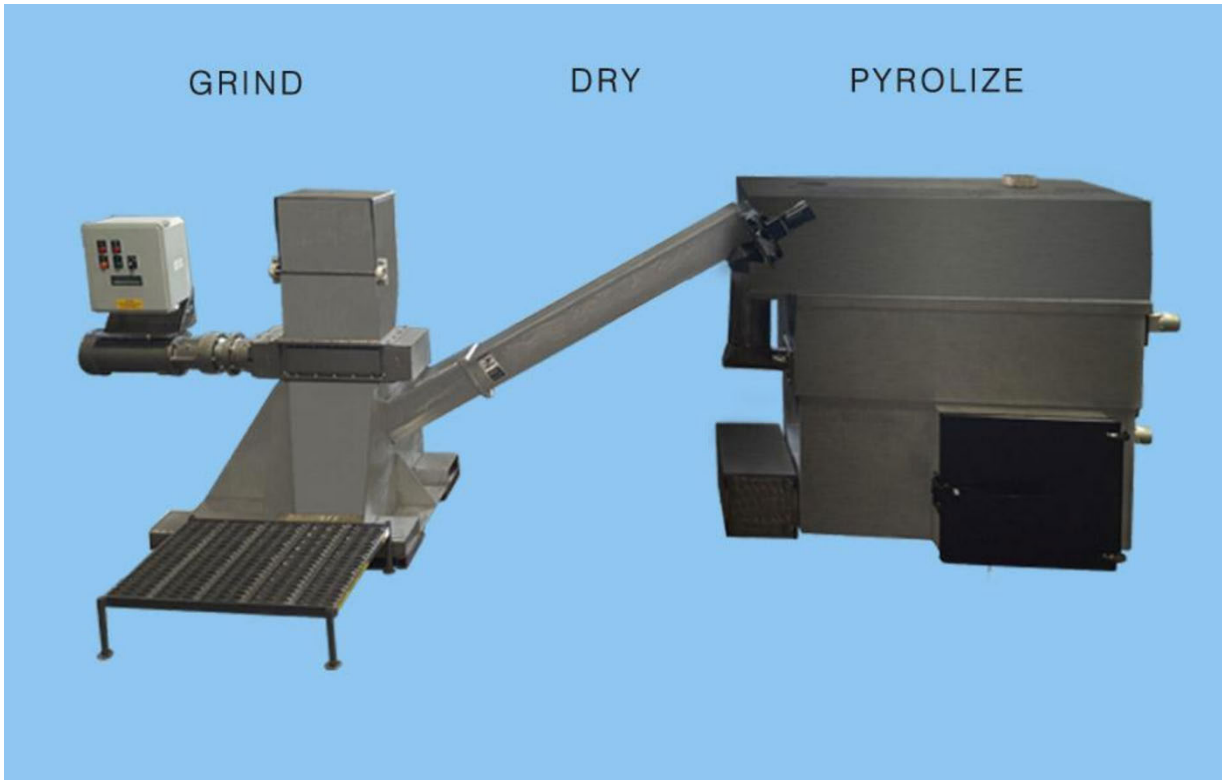
The System arrived in Kivalina on July 8, 2017, via delivery by an Alaska Marine Lines landing craft. As soon as required permits have been obtained, Re-Locate LLC will organize an operator training program to initiate local operations. [redacted]

System Specifications

The Kivalina Biogenic Refinery consists of three main components: the grinder, the transport auger, and the pyrolysis system. System components are built together and housed inside a single, 8x20' insulated shipping container. The container will rest on wooden dunnage sized to fit the container. The gross unit weight of the container is 14,300 pounds.

The System uses cardboard as fuel during start up. Once running, feedstock material is fed into the grinder by dedicated, trained operators. The grinder, designed for the waste industry, allows pre-processing of wipes or tissue paper which may be present in the feedstock. Ground material is fed by a transport auger for pyrolysis. During this phase, the System sustains pyrolysis by using thermal energy generated from the feedstock; no co-firing of fossil fuels or outside heating is required after system startup. After pyrolysis, the System employs a thermochemical process at the catalyst to refine emissions. Excess thermal energy generated by the System pre-dries feedstock as it moves through the transport auger. Air from the pre-processing grinder is pulled into the System through a carbon filter to control odor.

The System utilizes automated intelligent controls and a catalyst for managing pyrolysis and emissions.

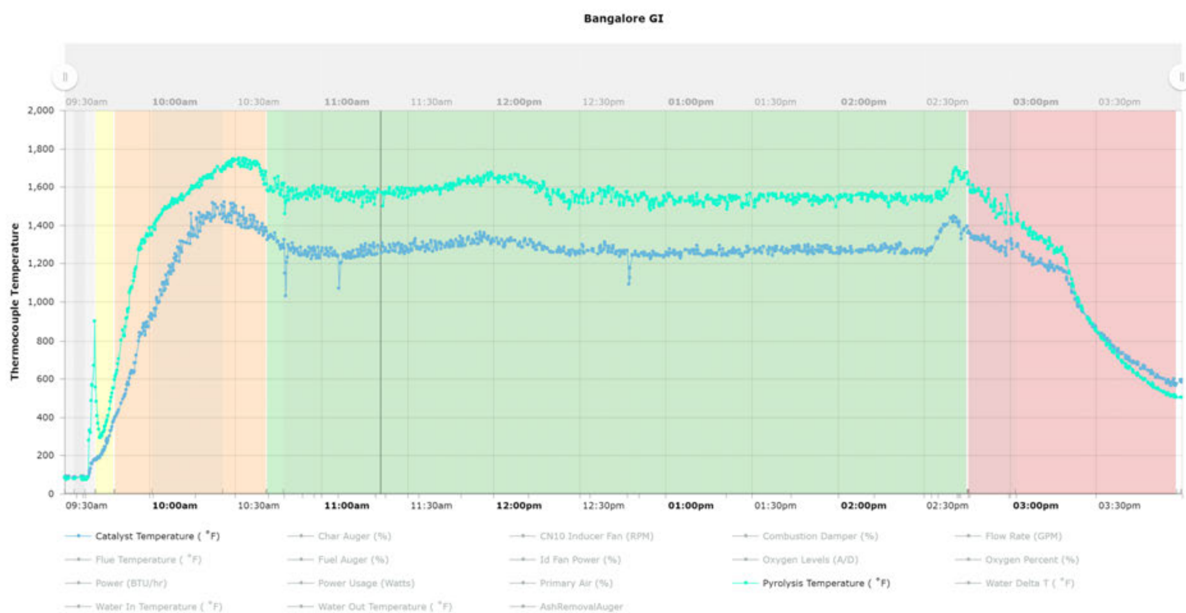


System illustration.

Pyrolysis Process
The feedstock undergoes pyrolysis in the pyrolysis pot, at temperatures between 600–900C. Pyrolysis temperature, heating rate, and residence time variables are optimized to reduce clinkers and minimize NOx and SOx emissions while ensuring a pathogen-free output. Feedstock is exposed to heat for approximately 20 minutes while moving through the Biogenic Refinery.

The Biomass Controls Intelligent Biofuel Controller uses oxygen sensors, thermocouples, thermistors, and pollution control technology to monitor System conditions. Variable Frequency Drives (VFDs) control oxygen levels by varying the amount of air that is added during the pyrolysis process. The control boards can adjust system conditions such as oxygen levels, feedstock fuel rates, biochar export rates, and pollution control to maintain pyrolysis. The control boards are microprocessor-based, have been in use since 2013, and have passed UL Certification under IEC 61010-1.

Time and Temperature Profile
The profile below charts time and temperature data from a Biogenic Refinery built for use by communities in Bangalore, India. The India refinery, also built by Biomass Controls, is an earlier model than the Kivalina model, but it uses the same pyrolysis process (similar time and temperature operations) as the Kivalina unit to process solid human waste.



Catalyst
After pyrolysis, System emissions undergo a thermochemical process by passing through a stainless-steel monolith catalyst coated with platinum and other noble metals. The catalyst is located approximately 3 feet from the pyrolysis chamber, and refines System emissions to CO_2 and gaseous H_2O before exhausting through the stack.

Power Requirements
The power requirement of the System during run state (steady state), or the maximum energy draw, was measured to be less than 600 watts/hour. The grinder, which will be operated intermittently, is rated to 3.7kW/hr. The System is designed to run fully off renewable wind and solar energy. We have not secured the funds needed to purchase the renewable energy hardware, so to initiate operations in Kivalina, we plan to draw power from an on-site 5 kWe generator.

Feedstock

System feedstock will be limited to solid human waste separated by UDDTs, in addition to toilet paper, wipes, wood pellets, and cardboard. No glass or metals can be processed.

UDDT Waste

UDDTs are waterless toilets whose ergonomic design separates urine and feces at the toilet. Dried solid waste collects and dries in a rotating bucket at the base of the UDDT that is lined with a biodegradable bag. Separated urine is batch discharged into the ground via a urine pipe. System users will collect the solid waste bag from the UDDT, seal the bag, and deliver it to a trained Kivalina Biogenic Refinery operator during open hours for processing. Because urine never comes into contact with the feces, UDDT solid waste has about a 35–40 percent moisture content. Kivalina families using UDDTs are emptying solid waste bags about 1–2 times per week.

Other Feedstocks

Cardboard: Cardboard, which has a high heat value (53,200 BTUs), purchased from the Kivalina Native Store and stored in a shipping container located adjacent to the System, will fuel System startup and shutdown. [redacted]

Wood pellets: One ton of purchased residential grade wood pellets arrived with the System upon delivery. A small amount of wood pellets will be used to preheat the System prior to adding the UDDT bags. Wood pellets will be stored with the cardboard in a shipping container adjacent to the System.

Toilet paper and wipes: The System is designed with an industrial grinder (Muffin Monster Industrial Grinder #111908) to process the toilet paper and wipes that accompany the bags of UDDT solid human waste.

Throughput

Trained operators will run the System 2 days/week for 8 hour daily shifts. The System will be cycled each time it is operated.

Output & Waste Volume Reduction

If the System processed 200 pounds of waste a per week, we would expect to produce 20 pounds of char per week (10 percent output). The Kivalina Biogenic Refinery can reduce UDDT waste volume by 90 percent and meets EPA Part 503 Biosolids criteria.

By-product biochar will be used for odor control within the System. Studies have shown that biochar can also be used for water filtration and as a soil amendment, however these uses are not being pursued for Kivalina. The biochar that has been used by the System to filter odor will be re-processed prior to disposal in the Kivalina landfill order to ensure a pathogen-free output.

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The Alaska Department of Environmental Conservation Air Permit Program, based on information Re-Locate LLC provided, determined that "combined annual emissions from both the System and the generator used to start the System would not trigger Alaska's minor permit thresholds in 18 AAC 50.502(c)(1). In addition, the capacity of the reactor is below the cumulative rated capacity threshold of 18 AAC 50.502(b)(4). Therefore, we believe the Kivalina Biochar Reactor does not require a Title I minor air quality permit with the State of Alaska under Article 5 of 18 AAC 50."

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Photo: Biochar produced by the System at Red Dog Port Site (14 miles from Kivalina), 12/16.

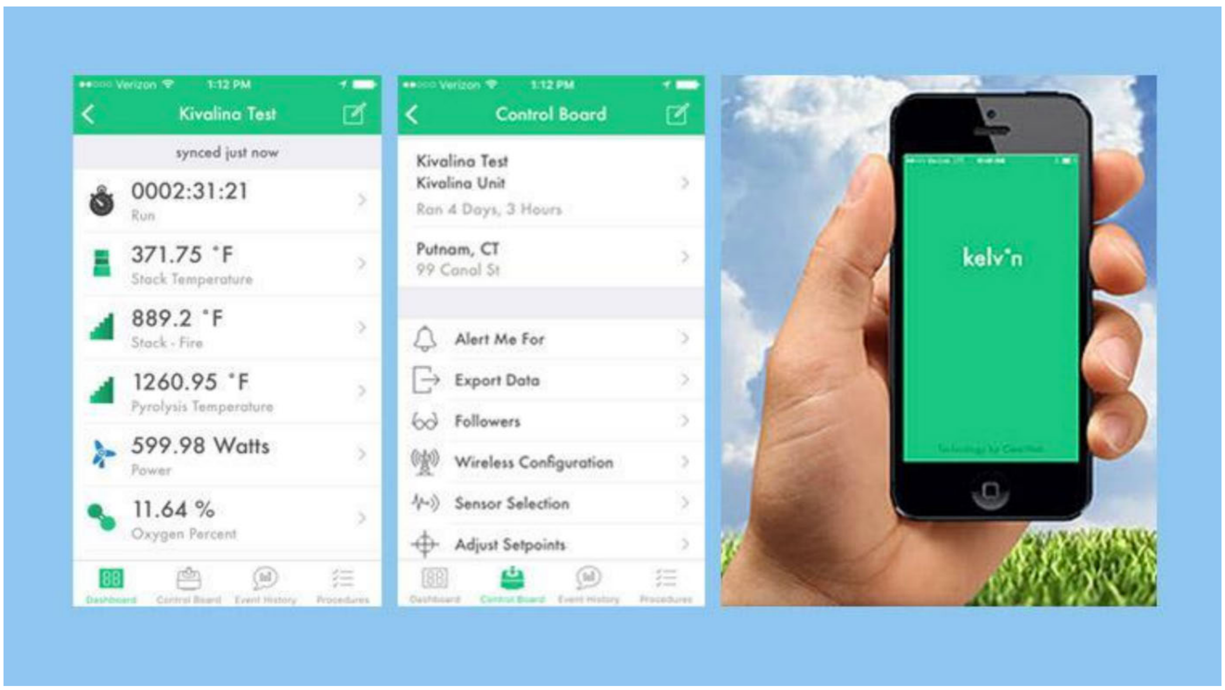
> The Alaska Department of Environmental Conservation Solid Waste Program issued Re-Locate LLC a letter of non-objection for disposing of System biochar in the Kivalina municipal landfill based on biochar having pathogen concentrations less than the untreated material that is currently dumped at the landfill. Once the Kivalina Biogenic Refinery is operational, pathogen concentrations in the Kivalina biochar will be confirmed by analytical testing.

Performance Monitoring and Data Analytics
The advanced controls and catalyst performance will be monitored through Biomass Controls's online mobile application called Kelvin. Kelvin is available for download through the Apple store and Google Play. This software platform includes remote monitoring and data capture capabilities, which integrate with smartphones to allow for decentralized management. Kelvin also provides a flexible user interface, which can be integrated into a variety of interactive technologies, to facilitate system performance management.

In remote locations, local operators can use Kelvin to communicate wirelessly, allowing for remote monitoring and management support from a distance. The software includes system analytics that can be exported for analysis. The mobile application platform also allows operators to pull and follow updated operating procedures. This ensures consistent operation of the Biogenic Refinery across users.

Kelvin also provides diagnostic functionality, alarms, and alerts to notify local operators and outside managers of System performance. System run data is fully accountable to allow for data-driven and results-based management of compliance, training, and System operation.

An example of a Kelvin reading taken during testing:



Permitting

As noted above, the AK DEC Solid Waste Division has issued Re-Locate LLC a letter of non-objection for disposing of biochar output at the Kivalina landfill and for reuse within the System as an odor filter. The State of Alaska Air Permits Program determined that the Kivalina Biogenic Refinery does not require a Title I minor air quality permit with the State of Alaska under Article 5 of 18 AAC 50. We are awaiting a determination from the EPA as to whether a federal air quality permit is needed.

Request for Determination
Based on the information we have provided above, we propose that the EPA regulate the System as a pyrolysis unit, which would make it exempt from Section 129 of the Clean Air Act. Please let either Jeff Hallowell or me know if you have further questions.

Sincerely,

Jennifer Marlow
Co-Owner, Re-Locate LLC
jen@re-locatellc.com
503.413.9524

Jeff Hallowell
President, Biomass Controls, LLC
jeff@biomasscontrols.com
877.524.6627 (877 5BIOMASS) x 701

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 10
1200 Sixth Avenue, Suite 155
Seattle, WA 98101-3123
SEP 20 2018

OFFICE OF
AIR AND WASTE

Jennifer Marlow
Co-owner
Re-Locate LLC

Re: Classification of Kivalina Biochar Unit Under Section 129 of the Clean Air Act

Dear Ms. Marlow:

This letter is in response to your letter to the United States Environmental protection Agency (EPA) dated August 10, 2017 inquiring about the classification of the Kivalina Biochar unit (the system) under section 129 of the Clean Air Act (the CAA). We are writing to clarify what steps you must take to demonstrate whether the system should be considered a process unit or a solid waste incineration unit and, therefore, whether it is subject to section 129 of the CAA.

Section 129 of the CAA requires the Administrator of the EPA to establish performance standards and other requirements, including the requirement to apply for and obtain a permit pursuant to title V of the CAA, for each category of solid waste incineration unit.[1] The term *solid waste incineration unit* is defined as any "distinct operating unit of any facility which combusts any solid waste material from commercial or industrial establishments or the general public." *See* section 129(g)(1) of the CAA. *Solid waste* has the same meaning as established in the Solid Waste Disposal Act (which was superseded by the Resource Conservation and Recovery Act or RCRA).

The requirements and procedures in 40 CFR part 241 identify whether certain non-hazardous secondary materials (i.e. byproducts, scraps, and other secondary materials) are, or are not, solid wastes when used as fuels or ingredients in combustion units under RCRA or the CAA. Materials that are determined to be wastes and are combusted must be combusted in solid waste incineration units meeting emission standards under section 129 of the CAA. Materials that are determined to be non-wastes can be used as fuels or ingredients in boilers, process heaters, or other units subject to emission standards under sections 111 and 112 of the CAA, as applicable.[2]

According to your description, the system processes, through pyrolysis, solid human waste and associated tissues and wipes received from urine diverting dry toilets (UDDT) installed in Kivalina homes, and produces a pathogen-free biochar product along with thermal energy. Wood pellets[3] and carboard serve as start-up fuels for the system. After pyrolysis, system emissions undergo a thermochemical process by passing through a stainless-steel monolith catalyst coated with platinum and other noble metals.

From the information submitted, it appears that the cardboard is being combusted and some combustion of the UDDT material is occurring in the unit. As discussed above, the cardboard provides heat to initiate an incomplete combustion process in a controlled oxygen environment with an end product of carbon-rich biochar. Considering

[1] These are sometimes called solid waste combustion units in the implementing regulations.
[2] We note that these units that are not incineration units are operated to produce steam, generate useful heat, generate useful mechanical work, or produce valuable products.
[3] As indicated in your letter, a small amount of wood pellets came with the system as a temporary start up fuel. The system will switch to cardboard when the wood pellets have been exhausted.

the reduction in mass (approximately 90 percent) and the fact that some oxygen is present during combustion, at least some of the UDDT waste, toilet paper, and wipes combust during the process. If *any* solid waste is combusted, a unit is considered a solid waste incineration unit.

Regarding applicability of part 241 to the materials used in the system (assuming use in a combustion unit), wood pellets are *clean cellulosic biomass*, and meet the definition of a *traditional fuel*, as those terms are defined in 40 CFR 241.2.

With limited exceptions, cardboard collected from commercial or industrial establishments or the public is generally considered a solid waste. For the cardboard to be considered a non-waste fuel in this circumstance, it could be demonstrated that the cardboard remains *within control of the generator* (as defined in 40 CFR 241.2), has not been discarded in the first instance, and meets legitimacy criteria for fuels in 40 CFR 241.3(d). As an alternative, where standards for defining *within control of the generator* cannot be met, a petition may be submitted to the Regional Administrator in accordance with 40 CFR 241.3(c) demonstrating that the material, even though it has been transferred to a third party, has not been discarded in the first instance, and meets legitimacy and other relevant criteria in 40 CFR 241.3(c) and (d).

Furthermore, for UDDT to be considered a non-waste ingredient, the material must meet legitimacy criteria in 40 CFR 241.3(d)(2), including the requirements that the material makes a useful contribution to the production of a valuable product. On page 6 of your letter you state that: "By-product biochar will be used for odor control within the System." Furthermore, "The biochar that has been used by the system to filter odor will be re-processed prior to disposal in the Kivalina landfill [in] order to ensure a pathogen-free output." Although your letter states how byproduct biochar will be used, it is also necessary to demonstrate that the system will produce a valuable product. Otherwise, the system would be seen as merely reducing the volume of waste, through incineration, prior to landfilling.

As a next step, we suggest that a you submit a letter to the Agency requesting a non-waste determination for the materials described above, together with relevant background materials that address the issues discussed. If you have any questions or would like to discuss this matter further, please contact Geoffrey Glass of my staff at (206) 553-1847 or glass.geoffrey@epa.gov.

Sincerely,

Kelly McFadden

Kelly McFadden, Manager
Stationary Source Unit

Cc: Jeff Hallowell, Biomass Controls, LLC

Biochar Reactor
Standard Operating Procedures
(“SOPS”)

Supplemental instructions for cold climate Biochar Reactors

Updated July 30, 2019

SAVE THESE INSTRUCTIONS
FOR FUTURE REFERENCE

Introduction

This document describes the Cold Climate Biochar Reactor, key safety requirements and safe handling of input materials and biochar. This is a companion guide to the FM200FA Cold Climate Operation and User’s Manual; updated November 16, 2016; this content supersedes portions of that publication. For information not contained herein, please refer to the manual.

Biomass Controls requires operators of the Biochar Reactor to wear appropriate personal protective equipment (“PPE”) including closed toe shoes and a dust mask during system operations. Please refer to the manual for further information about safety equipment and proper use.

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Facility Description

Kivalina Biochar Reactor

The Kivalina Biochar Reactor is a pilot health and sanitation project pursuant to Joint Resolution 15-01 of the City of Kivalina and the Native Village of Kivalina (February, 2015), updated in September, 2015. The Kivalina Biochar Reactor is designed to process solid human waste from Urine Diverting Dry Toilets (“UDDTs”) and refine the waste into biochar, a carbon-rich high-energy-dense solid.

The following information describes the Kivalina Biochar Reactor (the “System”).

Overview of the System

The Kivalina Biochar Reactor is a compact, community-scale, relocatable human solid waste refinery designed and built by Re-Locate LLC in partnership with Biomass Controls, LLC. The System processes solid human waste ingredients via pyrolysis (combustion in a low-oxygen environment) from Urine Diverting Dry Toilets (UDDTs) installed in Kivalina resident homes to produce pathogen-free biochar along with thermal energy in the form of heat. The system is rated to process 400 pounds per day of daily biogenic waste (dry basis). The thermal rating of the system is 175,000 BTUs.

System Specifications

The Kivalina Biochar Reactor consists of three main components: the grinder, the transport auger, and the pyrolysis system. The System utilizes controls and a catalyst for managing pyrolysis and emissions. The three pieces are built together and housed inside a single, 8x20’ insulated shipping container. The container will rest on wooden dunnage sized to fit the container.

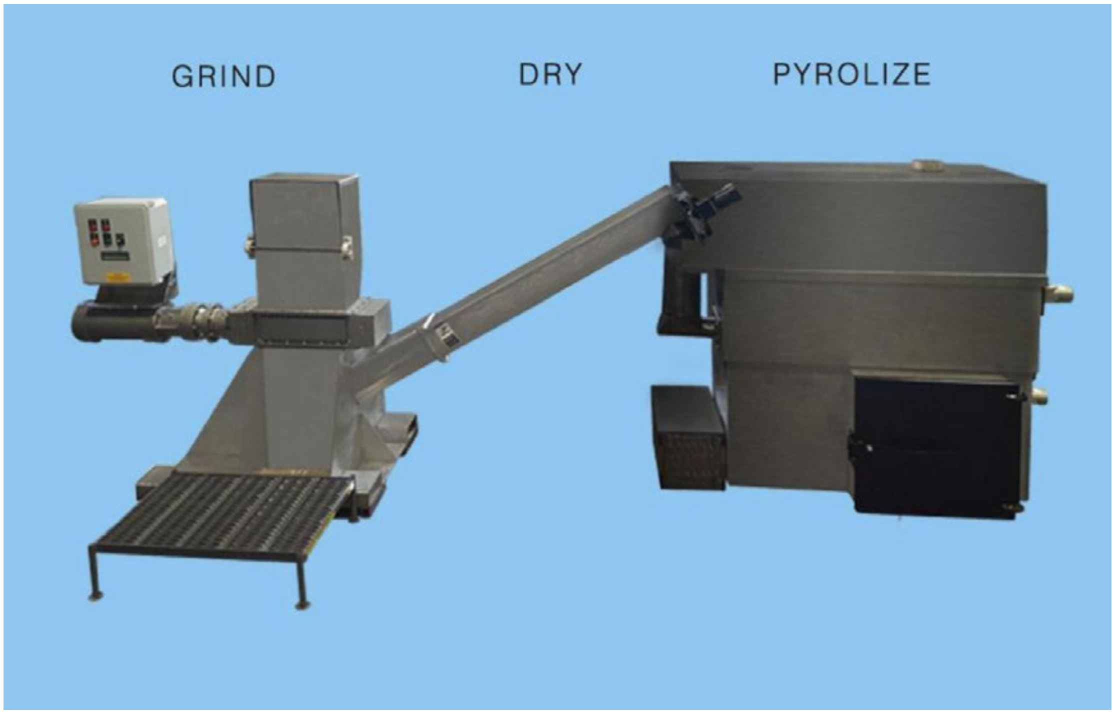

Image: Biochar Reactor Schematic

Designed to Process UDDT Waste

The System is designed to process solid human waste collected from homes in Kivalina utilizing Urine Diverting Dry Toilets—waterless toilets whose ergonomic design separates urine and feces at the house. Dried solid waste collects and dries in a rotating bucket at the base of the UDDT lined with a biodegradable bag, while separated urine is batch discharged into the ground via a urine pipe. System users will collect the solid waste bag from the UDDT, seal the bag, and deliver it to a trained Kivalina Biochar Reactor operator during open hours for processing. Because urine never comes into contact with the feces, UDDT solid waste has about a 35–40 percent moisture content. Kivalina families using UDDTs are emptying solid waste bags about 1–2 times per week.

Feedstock and Throughput

The feedstock utilized by the System will initially be limited to wood pellets, solid human waste separated by UDDTs, and toilet paper. Based on the current number of operational UDDTs, we are expecting to process 200 pounds of feedstock per week. The total volume of waste processed each week will increase if/when more UDDT toilets are added. The system is designed to accommodate a total throughput of 400 pounds/day (dry basis). One ton of residential grade wood pellets will arrive with the system inside the container. No glass or metals can be processed.

Biomass Controls Contact Information

To obtain service for your system, please contact Biomass Controls, PBC at +1 833.BIOMASS.

Biomass Controls
Putnam, CT | USA
Durham, NC | USA
+1 833.BIOMASS
www.BiomassControls.com

Safety Overview

Biomass Controls recommends the following safe practices when operating the system:

- Wear protective equipment
- Attend system training
- Report all hazards
- Hold each other accountable
- Triple check your work
- Keep all working areas clean
- Report all injuries
- Work as a team
- Look out for your fellow co-worker
- Communicate safe work practices
- Follow all standard operating procedures (SOP’s)
- Call for operational help
- Perform daily safety surveys
- Replace alarm batteries regularly
- Ensure all sensors are working properly
- Log generator use and maintenance
- Follow the Kelvin checklist
- Follow the SOPs

Operator safety is of extreme importance to Biomass Controls. To ensure maximum operator safety, Biomass Controls has provided safety checklist procedures in the Biomass Controls Kelvin application (free on Google Play and Apple Store). The operator(s) of the Biogenic Refinery must follow the procedures as outlined in the application. The application will prompt the operator to put on appropriate safety equipment and will not allow the procedure to continue unless the operator has checked off that the safety precautions have been met.

Biomass Controls requires a man door if the system is operated in a shipping container, to prevent the operator from being locked into the shipping container, or any other harmful scenario.

When operating the Biochar Reactor in a containerized setup, a fire extinguisher must be mounted in the container. A smoke alarm and a Carbon Monoxide (CO) alarm must also be present in the container to detect and alert the operator to any dangerous conditions. These should be regularly tested to be sure the alarms are working.

Biomass Controls recommends contacting Biomass Controls service personnel or another certified and trained electrician for any wiring assistance.

For safety purposes, chain guards have been provided on the system to cover the moving parts such as the gears and chains of the augers. The chain guards must be on the system while operating. If your system does not have a chain guard, do not operate the system; call Biomass Controls to report if there is a missing guard.

For safety purposes, Biomass Controls recommends verifying that the ventilation/draft controls in the area of operation are working properly each day. This is critical to ensure proper air circulation is achieved in the work area.

Biochar Reactor Input Requirements

Domestic septage processed by the Kivalina Biochar Reactor is exclusively limited to solid human waste separated in the homes that currently use Urine Diverting Dry Toilets (UDDTs).

Allowable input materials

- Cardboard
- Human solid waste

- UDDT bags
- Toilet Paper
- Wood Pellets

Prohibited input materials

The following materials are **NOT** permitted to be processed through the biochar reactor:
- Honeybucket bags
- Sanitary hygiene products (e.g. pads, tampons, diapers)
- Metals, including aluminum (this will contaminate and eventually deactivate the catalyst)
- Fishing line or other stringy materials
- Chemicals, specifically those listed in the *Banned Lists of Chemicals for the Cradle to Cradle Certified Product Standard, Version 3.0*
- Glass
- Trash
- Treated Wood
- Gasoline
- Petroleum-treated products
- Rubber
- Naptha[1]
- Input feedstock recently treated with herbicide
- Bones

Any of the above mentioned items may release toxic air pollutants, or deactivate emission control measures for expected pollutants.

Community UDDT Collection and Storage Procedures

Note: these site-specific instructions have been developed for Kivalina, Alaska Cold Climate Biochar Reactor and are not applicable for other systems.

[1] Naptha is any of several highly volatile, flammable liquid mixtures of hydrocarbons distilled from petroleum, coal tar, and natural gas and used as fuel, as solvents, and in making various chemicals.

In-Home Handling Procedures

Homeowners are to empty bags from their in-home UDDTs, seal the bags, and place them in a water tight and secured storage container at the exterior of the home. It is recommended that homeowners wear gloves while emptying and transporting the UDDT bags.

Homeowners are responsible for appropriately using the UDDT system, including:

- Disposing of household waste in appropriate receptacles, not in the UDDT
- Disposing of sanitary waste (pads, tampons, diapers) in the trash not in the UDDT
- Never placing any other items other than toilet paper in the UDDT bags

Collection, Transportation and Storage of UDDT Materials

1. Trained System Operators collect UDDT bags from containers at the exterior of homes on a posted schedule. Wintertime collection is done using a snowmachine and sled. Summertime collection is done using a 4 Wheeler and wagon.
2. Trained System Operators deliver UDDT bags to the System for processing, where they are staged prior to processing in an on-site watertight and secured container
3. Trained System Operators run the System on a set weekly schedule, with the number of days of operation to be determined and as required to process the UDDT materials collected from the community. Furthermore:
    a. All tasks are performed by trained System Operators who are held to the SOPs developed by the System manufacturer;
    b. The System is a batch operated (started and stopped as necessary and not continuously operated) system; System Operators will process UDDT materials on the same day that UDDT materials are collected;
    c. All UDDT bags will be stored on-site for processing for less than 24 hours from the time they are collected;
    d. No UDDT waste that is not staged to be fed into the System will be stored on site or permitted to be stored overnight so as not to attract varmints;
    e. UDDT ingredients will only be processed during open hours of operation.

Handling Biosolids

Biomass Controls requires operators of the Biogenic Refinery to wear safety glasses, high temperature rated gloves, and a dust mask during operation.

Biomass Controls recommends adding a Biohazard sign onto the Biogenic Refinery if the system will be used to process fecal matter/sludge/septage/biosolids or any other type of biohazardous infectious material.

When handling biosolids, Biomass Controls recommends the following guidelines as provided by the Centers for Disease Control and Prevention (CDC), originally developed by the United States Environmental Protection Agency (EPA), for protecting the operators. Basic hygiene precautions are important for workers handling biosolids. Note that it is critical for operators to assess any additional safety precautions that may be required.

The following list provides a good set of hygiene recommendations:

- Wash hands thoroughly with soap and water after contact with biosolids.
- Avoid touching face, mouth, eyes, nose, genitalia, or open sores and cuts while working with biosolids.
- Wash your hands before you eat, drink, or smoke and before and after using the bathroom.
- Eat in designated areas away from biosolids-handling activities.
- Do not smoke or chew substances (such as tobacco or gum) while working with biosolids.
- Use barriers between skin and surfaces exposed to biosolids.
- Remove excess biosolids from footgear prior to entering a vehicle or a building.
- Keep wounds covered with clean, dry bandages.
- Thoroughly but gently flush eyes with water if biosolids contact eyes.
- Change into clean work clothing on a daily basis and reserve footgear for use at worksite or during biosolids transport.
- Do not wear work clothes home or outside the work environment.
- Use gloves to prevent skin abrasion.

UDDT materials are not to be stored longer than 24 hours on-site prior to processing. Only those materials delivered during open hours will be processed by the system.

Handling and Storage of Biochar

These recommendations are based on guidelines from the European Biochar Foundation, International Biochar Initiative, and EPA Part 503 Biosolids Rule. Biomass Controls recommends reviewing these in full using the following links:
http://www.european-biochar.org/biochar/media/doc/ebc-guidelines.pdf,
https://www.biochar-international.org/wp-content/uploads/2018/04/IBI_Pyrolysis_Plant_Guidelines.pdf,

https://www.epa.gov/sites/production/files/2018-12/documents/plain-english-guide-part503-biosolids-rule.pdf.

Care should be taken when opening and unloading the biochar box. Appropriate safety equipment for heat and dust should be worn whenever handling biochar, including:

- Eye protection (safety glasses, goggles)
- Lung protection (mask, ventilator)
- Ear protection (ear plugs, ear muffs)
- Heat protection (appropriate gloves, clothing)
- Foot protection (steel capped boots)

It is recommended to quench the biochar prior to removal by spraying a small amount of water on it prior to removal from the system.

If appropriate, the biochar should be stored in sealed containers or vessels and stored in a covered area, protected from wind and rain, and far from fire hazards. The biochar may also be disposed at the landfill.

[redacted] [redacted]

[redacted]

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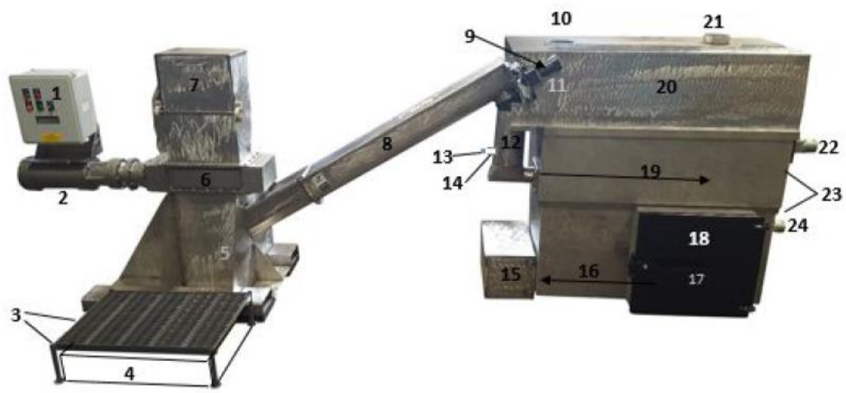

1. Grinder Control Box
2. Grinder Motor
3. Odor Box Inducer Fan(s) Position
4. Odor Box Position
5. Pre-Processing Door Hinge Switch (rear)
6. Grinder (enclosed)
7. Feed/Mailbox Chute
8. Pre Processing Transport Auger
9. Pre Processing Transport Motor
10. Stack Position
11. Forced Air Heat Exchanger Fan (Enclosed)
12. Fuel Hopper
13. Temperature Limit Switch
14. Bindicator (Position/Enclosed)
15. Biochar Collection Box
16. Biochar Transport Auger
17. Pyrolysis Pot (enclosed)
18. Carbonizer Door
19. Fuel Transport Auger (enclosed)
20. Forced Air Heat Exchanger
21. Inducer Fan Position
22. Fuel Transport Auger Motor
23. Drive Chain(s)
24. Biochar Transport Auger Motor

Contaminant Concentrations in Traditional Fuels:
Tables for Comparison

November 29, 2011

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In an effort to provide additional information and data to the regulated community concerning the concentrations of contaminants that may be found in traditional fuels, the following tables present summary statistics for contaminant concentrations in common traditional fuels. Members of the regulated community may find the data presented here useful when comparing contaminants in their non-hazardous secondary materials (NHSMs) to contaminants in the appropriate traditional fuels.[1]

- Use of these tables is not required to demonstrate compliance with the contaminant legitimacy criterion, and the existence of these tables does not preclude the use of other data sources. EPA has organized and presented this data as a service to assist NHSM processors and combustors in making contaminant comparisons. The Agency will periodically update these tables as additional data become available.

- The following three tables cite contaminant data from both the scientific literature and EPA databases for coal, wood/biomass, and fuel oil. NHSMs burned in combustion units are most often substituted for one of these three traditional fuels.

- The two referenced EPA databases, both compiled by the Agency's Office of Air Quality Planning and Standards (OAQPS), together contain approximately 32,000 records of contaminant analyses performed on coal (~17,000), wood/biomass (~12,000), or fuel oil (~3,000) samples prior to combustion. Summary statistics from this comprehensive dataset are displayed separately from other data sources, but persons using these tables to make contaminant comparisons are not constrained to one column or one data source for the appropriate traditional fuel.

[1] All data presented in this document are for individual contaminants for which EPA has information. Please note that targeted revisions to the rule are under development, with the goals of both clarifying the 40 CFR Part 241 requirements and facilitating implementation of the rule as EPA originally intended. EPA is considering including a discussion of contaminant groups (e.g., VOC), an alternate option for contaminant comparisons involving hazardous air pollutant compounds that NHSM processors and combustors may want to consider.

Table 1: Contaminant Concentrations in Coal[1]

Contaminant	Units	Literature Sources	OAQPS Databases[2]		
		Range	Range	Average[3]	Non-Detect Rate
Metal elements - dry basis					
Antimony (Sb)	ppm	0.5 - 10[4]	ND - 6.9	1.7	25 %
Arsenic (As)	ppm	0.5 - 80[4]	ND - 174	8.2	8 %
Beryllium (Be)	ppm	0.1 - 15[4]	ND - 206	1.9	12 %
Cadmium (Cd)	ppm	0.1 - 3[4]	ND - 19	0.6	38 %
Chromium (Cr)	ppm	0.5 - 60[4]	ND - 168	13.4	1 %
Cobalt (Co)	ppm	0.5 - 30[4]	ND - 25.2	6.9	8 %
Lead (Pb)	ppm	2 - 80[4]	ND - 148	8.7	5 %
Manganese (Mn)	ppm	5 - 300[4]	ND - 512	26.2	<1 %
Mercury (Hg)	ppm	0.02 - 1[4]	ND - 3.1	0.09	5 %
Nickel (Ni)	ppm	0.5 - 50[4]	ND - 730	21.5	<1 %
Selenium (Se)	ppm	0.2 - 10[4]	ND - 74.3	3.4	22 %
Non-metal elements - dry basis					
Chlorine (Cl)	ppm	--	ND - 9,080	992	4 %
Fluorine (F)	ppm	--	ND - 178	64.0	9 %
Nitrogen (N)	ppm	--	13600 - 54000	15090	0 %
Sulfur (S)	ppm	--	740 - 61300	13580	0 %
Hazardous air pollutant (HAP) compounds[5]					
Benzene	ppm	ND - 38[6]	--	--	--
Ethyl benzene	ppm	0.7 - 5.4[6]	--	--	--
16-PAH	ppm	6 - 253[7]	--	--	--
PAH (52 extractable)	ppm	14 - 2090[7]	--	--	--
Styrene	ppm	1.0 - 26[6]	--	--	--
Toluene	ppm	8.6 - 56[6]	--	--	--
Xylenes	ppm	4.0 - 28[6]	--	--	--

Sources and Notes:

1. This table includes data for anthracite, bituminous, sub-bituminous, and lignite coal.
2. USEPA, Office of Air Quality Planning and Standards (2011a & 2011b).
3. Averages are weighted averages of individual facilities responding to the OAQPS survey. Averages only include samples above detection limits.
4. Clarke and Sloss (1992).
5. HAPs listed here include only those HAPs with available data. These are not the only HAP compounds considered contaminants.
6. Fernandez-Martinez (2000).
7. Laumann, et al. (2011).

Table 2: Contaminant Concentrations in Wood & Biomass Materials[1]

Contaminant	Units	Literature Sources	OAQPS Databases[2]		
		Range	Range	Average[3]	Non-Detect Rate
Metal elements — dry basis					
Antimony (Sb)	ppm	ND - 26[4]	ND - 6.0	0.9	45 %
Arsenic (As)	ppm	ND - 6.8[4]	ND - 298	6.3	57 %
Beryllium (Be)	ppm	--	ND - 10	0.3	69 %
Cadmium (Cd)	ppm	ND - 3[4]	ND - 17	0.6	32 %
Chromium (Cr)	ppm	ND - 130[4]	ND - 340	5.9	14 %
Cobalt (Co)	ppm	ND - 24[4]	ND - 213	6.5	23 %
Lead (Pb)	ppm	ND - 340[4]	ND - 229	4.5	28 %
Manganese (Mn)	ppm	7.9 - 840[4]	ND - 15800	302	<1 %
Mercury (Hg)	ppm	ND - 0.2[4]	ND - 1.1	0.03	22 %
Nickel (Ni)	ppm	ND - 540[4]	ND - 175	2.8	17 %
Selenium (Se)	ppm	ND - 2[4]	ND - 9.0	1.1	69 %
Non-metal elements — dry basis					
Chlorine (Cl)	ppm	ND - 2600[4]	ND - 5400	259	5 %
Fluorine (F)	ppm	ND - 300[4]	ND - 128	32.4	43 %
Nitrogen (N)	ppm	200 - 39500[4,5]	2200 - 4600[5]	3460	0 %
Sulfur (S)	ppm	ND - 8700[4]	ND - 6100	704	5 %
Hazardous air pollutant (HAP) compounds[6]					
Formaldehyde	ppm	1.6 - 27[7]	--	--	--

Sources and Notes:

1. This table includes data for untreated wood and biomass, including bark, bagasse, hog fuel, and agricultural plant residues.
2. USEPA, Office of Air Quality Planning and Standards (2011a & 2011b).
3. Averages are weighted averages of individual facilities responding to the OAQPS survey. Averages only include samples above detection limits.
4. Energy Research Centre for the Netherlands, Phyllis Biomass database. http://www.ecn.nl/phyllis.
5. OAQPS nitrogen range based on 20 samples from two facilities, whereas Phyllis biomass database nitrogen range reflects the results of 394 studies.
6. HAPs listed here include only those HAPs with available data. These are not the only HAP compounds considered contaminants.
7. T. Hunt (2011).

Table 3: Contaminant Concentrations in Fuel Oils[1]

Contaminant	Units	Literature Sources	OAQPS Databases[2]		
		Range	Range	Average[3]	Non-Detect Rate
Metal elements - dry basis					
Antimony (Sb)	ppm	ND - 15.7[4]	ND - 3.8	3.5	97 %
Arsenic (As)	ppm	--	ND - 13	1.3	72 %
Beryllium (Be)	ppm	--	ND - 19	2.3	73 %
Cadmium (Cd)	ppm	--	ND - 1.4	0.4	75 %
Chromium (Cr)	ppm	--	ND - 37	3.7	65 %
Cobalt (Co)	ppm	--	ND - 8.5	1.1	84 %
Lead (Pb)	ppm	ND - 56.8[4]	ND - 52	4.3	46 %
Manganese (Mn)	ppm	--	ND - 3200	118	49 %
Mercury (Hg)	ppm	--	ND - 0.2	0.02	74 %
Nickel (Ni)	ppm	ND - 50.2[4]	ND - 270	24.1	39 %
Selenium (Se)	ppm	--	ND - 4	0.8	74 %
Non-metal elements - dry basis					
Chlorine (Cl)	ppm	--	ND - 1260	133	35 %
Fluorine (F)	ppm	--	ND - 14[5]	8.5	80 %
Nitrogen (N)	ppm	42 - 8950[4]	2000 - 3000[6]	2250	0 %
Sulfur (S)	ppm	--	ND - 57000	8280	9 %
Hazardous air pollutant (HAP) compounds[7]					
Benzene	ppm	ND - 75[4]	--	--	--
Biphenyl	ppm	1000 - 1200[8]	--	--	--
Cumene	ppm	6000 - 8600[9]	--	--	--
Ethyl benzene	ppm	22 - 1270[8]	--	--	--
Hexane	ppm	50 - 10000[8]	--	--	--
Naphthalene	ppm	ND - 7330[8]	--	--	--
Total PAH	ppm	3900 - 54700[4]	--	--	--
Phenol	ppm	ND - 7700[8]	--	--	--
Styrene	ppm	ND - 320[8]	--	--	--
Toluene	ppm	ND - 380[4]	--	--	--
Xylenes	ppm	ND - 3100[8]	--	--	--

Sources and Notes:

1. This table includes data for fuel oils 1-6, including distillate, residual, kerosene, diesel, and other petroleum based oils. It does not include data for gasoline or unrefined crude oil.
2. USEPA, Office of Air Quality Planning and Standards (2011a & 2011b).
3. Averages are weighted averages of individual facilities responding to the OAQPS survey. Averages only include samples above detection limits.
4. U.S. EPA (1999), Appendix B.
5. OAQPS fluorine range based on a limited dataset (59 samples from only five facilities). Detection limits for non-detect results ranged from 19 to 300 ppm, all higher than the maximum recorded value of 14 ppm.
6. OAQPS nitrogen range based on a limited dataset (12 samples from only one facility).
7. HAPs listed here include only those HAPs with available data. These are not the only HAP compounds considered contaminants.
8. USEPA (2000).
9. World Health Organization (1999).

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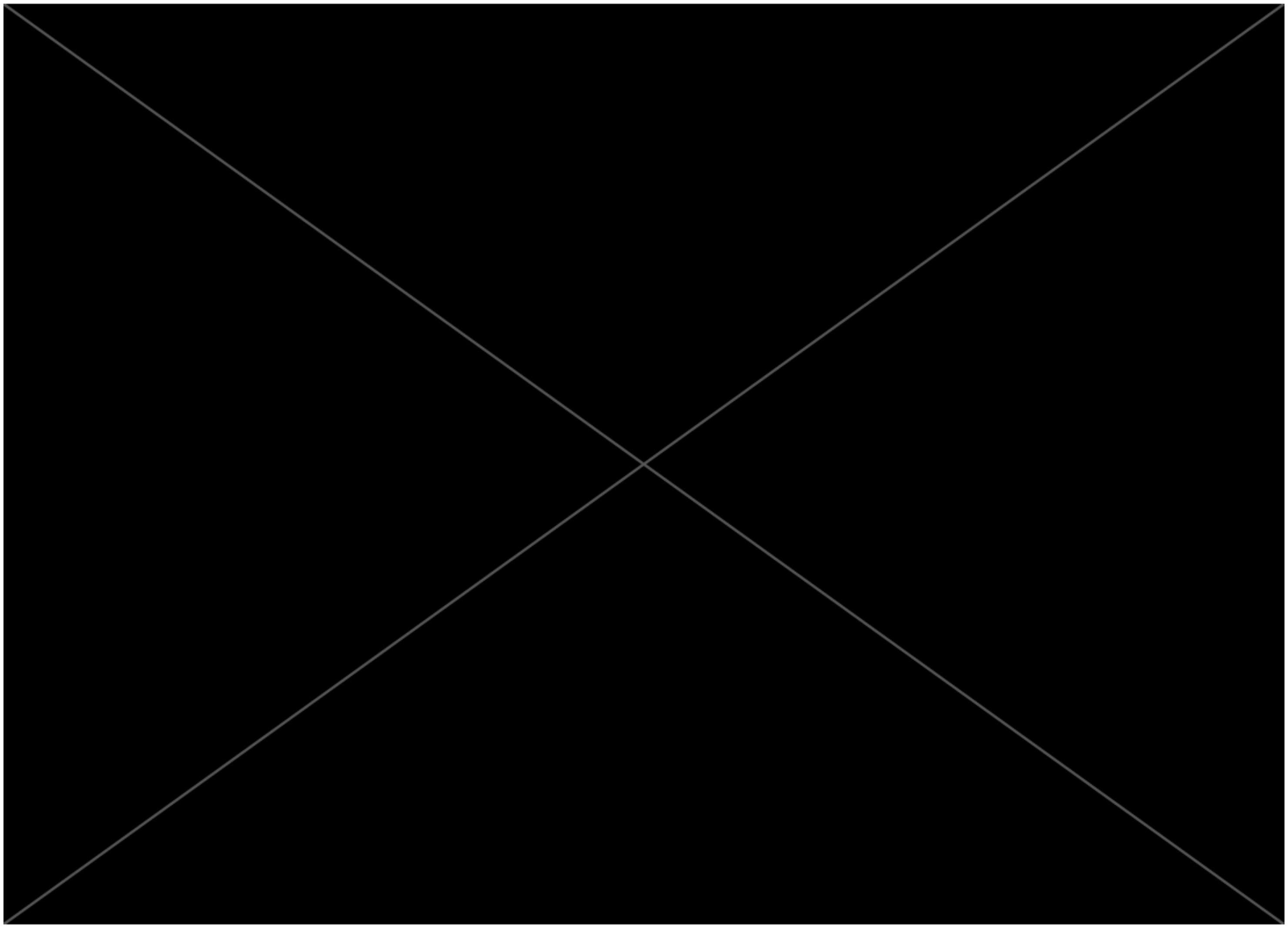

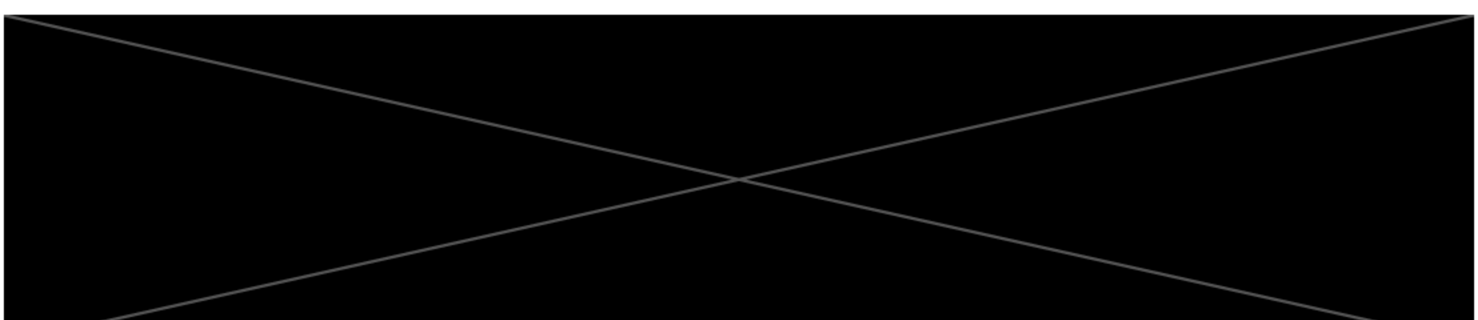

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SURVEY AND ANALYSIS OF THE US BIOCHAR INDUSTRY

November 2018

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Survey and Analysis of the US Biochar Industry

Introduction

The US market potential for biochar is estimated at over 3 billion tons.[1] However, there are many factors affecting the development of that market, including: technology, quality standards, education and marketing, and economics. Dovetail Partners, the US Biochar Initiative (USBI), the International Biochar Initiative (IBI) and The Watershed Research and Training Center have collaborated on an assessment of the state of the biochar industry. The objective is to define the scope and scale of the North American biochar market, and quantify its potential for woody biomass utilization. The study results identify constraints of the current production system and identify gaps requiring further attention. The supply potential from National Forests is a specific consideration within the research. National Forests in many regions are located in close proximity to agricultural lands (i.e., potential biochar users) and have the potential to be a major supplier of woody biomass due to management and restoration needs on National Forests.

Forestlands across the US are in need of improvement and restoration. Forest practitioners are in need of additional profitable avenues for low-value woody biomass. Biochar has been an emerging market for at least a decade and is characterized currently by a few large and many small producers, all pursuing profitable operations. The industry is in a stage of rapid technological developments which appear to offer the potential for a mid-range producer-class to emerge, but the demand for large quantities of biochar has been hampered by reluctant buyers due to the lack of consistent standards, unverified claims, and widely varying price and availability. This report identifies the key next steps in realizing the potential for the US biochar industry including establishing standards, a comprehensive marketing initiative, and testing to validate biochar's application benefits.

Executive Summary

Biochar is a commercially produced product resulting from the pyrolysis of plant-based biomass. The markets and uses for biochar are rapidly expanding, as are its production technologies and capacities, and its sales.[2]

Biochar feedstocks are woody debris, manure litters, and ag and other organic wastes. Since the largest volume feedstock source is from woody biomass historically, the US Forest Service is interested in biochar as a large scale user of unsalable products from fire salvage, habitat restoration, and wildfire reduction projects. This report summarizes the surveys and analysis of US industrial biochar producers and users.[3]

[1] The USDA's National Agricultural Statistical Service reported there were 318 million planted cropland acres in 2010. It takes 9.4 tons of carbon per acre to increase soil carbon content by 1%; therefore, almost 3 billion tons (6.1 million railcars) of biochar would be needed to enhance all U.S. cropland. For further discussion of market estimates, see reports listed in footnote 2.

[2] For background information on biochar see past Dovetail reports: *Biochar 101: An Introduction to an Ancient Product Offering Modern Opportunities* www.dovetailinc.org/report_pdfs/2016/dovetailbiochar0316.pdf and *Biochar as an Innovative Wood Product: A Look at Barriers to Realization of its Full Potential* http://www.dovetailinc.org/report_pdfs/2017/dovetailbiocharpotential0517.pdf

[3] The survey questionnaires are appended to this report.

Out of an estimated 135 biochar producers in the US, responses were received from 61, a 45% response rate. The User survey elicited 58 responses from domestic users. The analyses were based on these responses in addition to follow-up interviews by phone and in person. The August 2018 US Biochar Initiative (USBI) Biochar Conference provided additional timely data for our analysis from presentations, posters, as well as group and individual discussions.

The two surveys are complementary in their results and were reinforced by follow-up interviews, presentations, and discussions at the Biochar Conference. Two trends stand out:

- Growth in sales is supported by a general optimism in the strength of the marketplace.
- A widespread desire for more information and support from all resource entities.

The outcomes of the survey, supported by a distillation of Biochar Conference outputs point to a three prong strategy to grow the industry:

1. Both biochar producers and users see the need for more attention to be paid to the characteristics and quality of the end product. Taking steps to develop widely accepted standards are recognized as vitally important.
2. Biochar producers and users see the need for public and customer education—in support of biochar as a desirable and sought after product.
3. Producers and users understand the need to validate scientifically any claims to be made about the benefits of using biochar.

The challenge with implementing this strategy is establishing a credible basis on which to make product claims. However, once the science to back-up claims legally is identified and reinforced by a framework of standardized product characteristics, the industry is poised to capitalize on that research and those standards to support both increased public awareness and sales.

Methodology

A survey and analysis of the US biochar industry was conducted by the project team consisting of:

- Kathleen Draper, Finger Lakes Biochar and Ithaka Journal; NY
- Harry Groot, Dovetail Partners, Inc.; Minneapolis MN
- Tom Miles, Tom Miles Consulting, Inc. and US Biochar Initiative; Portland, OR
- Martin Twer, Biomass Program Director, The Watershed Research & Training Center; Hayfork, CA

Two surveys were conducted; one for producers and one for users. The survey was composed online and the US Biochar Initiative mailed the invitations and follow-up requests. The specific survey input was treated as confidential; however, a field was provided to allow individuals to authorize follow-up—which was conducted with selected respondents by project team members.

Out of an estimated 135 biochar producers in the US, responses were received from 61, a 45% response rate. The User survey elicited 58 responses from domestic users in a parallel survey. The analysis was based on these responses in addition to follow-up interviews by phone and in person.

All members of the project team participated in the data compilation, analysis, and reporting. Due to the mailing list used to invite the biochar community's participation in the surveys, there were 69 total respondent producers, but 7 were Canadian and one was German; their data has been segregated. All 58 responding Users were domestic.[4]

US Biochar Market Background

Prior to this survey, the US biochar industry production was estimated to be between 15,000-20,000 tons per year (TPY) by USBI. This survey provides data to support an estimate of 35,000 to 70,000 TPY. Based on anecdotal input gathered at the 2018 USBI Biochar Conference about the production rates of some of the larger producers, even that estimate is probably conservative; however, the basis used in this report is 45,000 TPY.

Using a 75% reduction in dry weight from raw feedstock to finished biochar, biochar production of 45,000 TPY would consume about 200,000 bone dry tons (BDT) of biomass as feedstock. Knowing that most feedstock ranges from 20 to 60% moisture content (for woody and ag biomass, the most common feedstocks) it can be extrapolated that the industry uses between 125,000 to 250,000 delivered tons of feedstock.[5]

The users represent a usage of 163 to 200+TPY, less than 1% of industry's projected production capacity. There is no way to know what percentage of all consumers this represents, but the project team solicited their input to better understand issues rather than to gain a comprehensive picture of market demand.

Producers Survey Results

The producer responses came from a broad cross section of the industry with the smaller producers being in the majority (Figure 1). The analysis focused on the larger producers (above 100 TPY) to reflect the interest in increased utilization of woody biomass. To date there is no definitive data on the size and distribution of US biochar production, only an estimate based on on-line research, and personal knowledge of consultants familiar with industry players.

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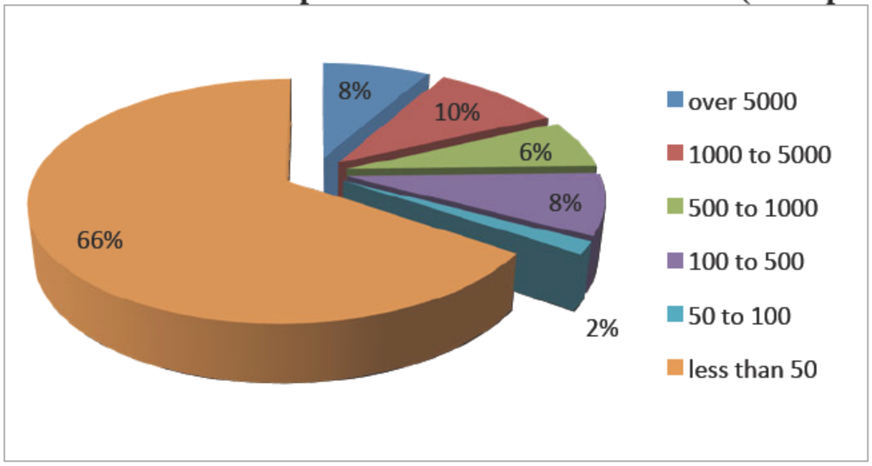
[4] Some of the data presented is based on the entire response set and is noted as such; however, to reflect "the industry" most accurately, the higher volume producers and users have been broken out from smaller-scale producers and users who are typically hobbyists and not production oriented. The team's concern is that including the small-scale data skews the industry-focus of this study.

[5] To put this in perspective: A September 2018 fact finding trip by USBI to China, including a tour of one biochar plant, returned with this announcement: *Leading the world in large scale biochar production, China is on their way to building 200 pyrolysis facilities that will each produce 30 kilotons of biochar per year. Using crop waste as their main feedstock, the biochar is processed into slow release fertilizer before being distributed to farmers. Albert Bates, USBI Board Member, sees this as only the beginning, as China will be able to offer new biochar plant designs all along their New Silk Road and expand biochar applications beyond agriculture. [This will be a productive capacity of 6Million Tons of biochar annually, using 24M BDT of biomass*.]
https://myemail.constantcontact.com/IBI-Asia-China-Workshop.html?soid=1130041240013&aid=FL7kdv-OT-M

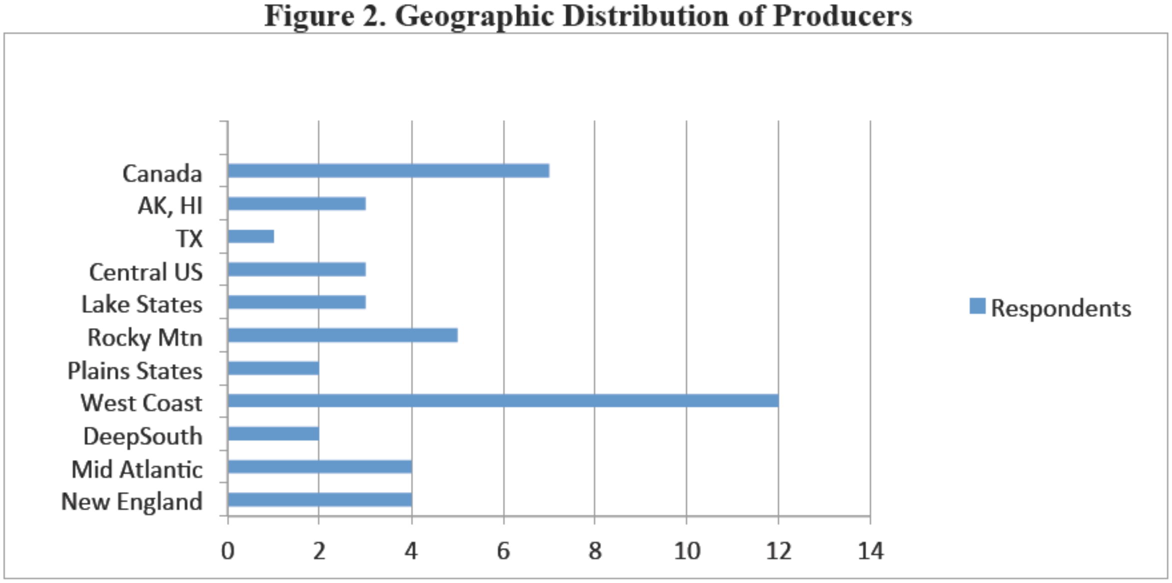
Figure 1. Distribution of Respondent Producer's Production (Tons per Year)



The domestic biochar production represented by the survey respondents is between 35,000 and 70,000 Tons per year. The Canadian production adds an additional 1,700 to 6,600 TPY for a North American total of 36,700 to 76,600 TPY.

Figure 2 shows the respondent's geographic distribution and the strength of the industry in the US (and Canadian) West. While there have been news releases announcing intended large scale production projects in the Eastern US, the industry's development has been led by Western US producers since its inception.[6]

Figure 2. Geographic Distribution of Producers



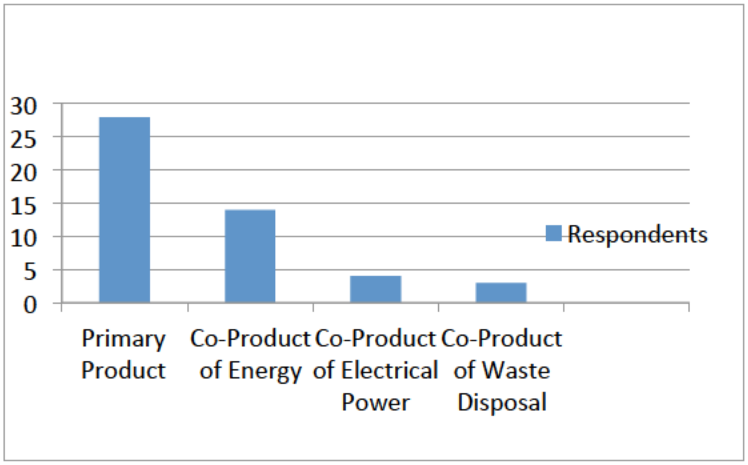
Larger producers have been in business, on average, longer than most of the intermediate sized producers (at over 5 years) however there were 9 firms producing less than 100 TPY with more

[6] *A note about the following data presentation:* *The larger producers were relatively thorough in responding to the survey questions, so while there is a fairly consistent 25 to 30% non-response rate on a question-by-question basis, it affects the lower 10 to 20% of the volume of biochar producers for the most part. This analysis' focus on volume producers captures that bias.*

than 5 years production experience. Given that experience base, compared to other industries, the relative "newness" of biochar as a commercial product is evident.

Figure 3 provides a look at the biochar production methods represented; 57% of the respondents were biochar producers primarily, with 29% as a byproduct of energy generation and 8% as a byproduct of electricity generation[7].

Figure 3.
Biochar Production Methods



Eighty-two percent of the respondents were producers and 18% were resellers only. Of the 14 resellers, only two purchased between 1000 and 5000 tons per year while 4 purchased between 100 and 500 Tons, and 8 purchased less than 50 Tons per Year.

Producers sell most of their biochar for agricultural uses: gardens, field crops, orchards, horticultural applications, turf, and landscaping. The table below shows for which applications producers and resellers are selling biochar specifically (Table 1).

Table 1. Biochar Applications

Garden	*62%*
Horticulture, specialty crops	*47%*
Field Crops	*42%*
Orchard or tree crops	*29%*
Turf	*20%*
Landscaping	*36%*
Stormwater, filtration	33%
Odor control	27%
Other	18%

The *italicized* uses are aggregated under an "Agricultural" class.
The "other" category includes concrete admixture and pigments.

[7] Energy Generation is defined as the process where heat is extracted using air or water for some downstream process; Electrical generation may produce those energy streams, but is considered primarily a process to generate electricity. In order to produce biochar the combustion process of both systems have to be managed differently (and generally at a lower energy efficiency) than producing process heat or power only.

Of the largest volume producers (23 respondents over 100TPY), 43% (10) make biochar for no specific end use. Thirty five percent (9) make biochar for agricultural applications specifically, 9% (2) for drainage, and 13% (3) for odor control specifically.
Five of the largest volume producers sell their biochar as-is. Twelve of them process further (sizing, pelletizing, charging/inoculating/activating, neutralizing pH, and/or mixing with other soil amendments) (see sidebar for discussion).

Biochar is supplied in bag, bucket, or barrel or in bulk as specified by the customer in the following forms (in rank order):

1. Coarse chips
2. Fine powder
3. Fine screened chips
4. Pellets
5. Granules or prills
6. Liquid suspension.

Most of the large suppliers responding (39%, 9) do not pursue any independent certification; however 5 have OMRI (Organic Materials Review Institute) listing or USDA Organic certification and 5 use IBI standards[8].

Biochar Downstream Processes

- Biochar is sized to allow optimized field application or mixing with other amendments/products.
- Since biochar is typically basic (higher pH) it may need to be buffered or neutralized.
- Since biochar is a sterile substrate with huge surface area (like activated carbon) it acts as a host for soil microbial growth and for chemical bonds. So users often "charge" the raw biochar to fill those voids with desirable and predictable substances. For instance, a popular technique is to soak the biochar in an activated compost tea.

The majority of biochar is shipped locally and regionally (less than 500 miles), however exports are being made to Europe, Asia, Australia and the Middle East by producers in all production classes. Responding producers and resellers were evenly split on customer requests to know whether the biochar was locally sourced, with smaller scale producers asked most often.

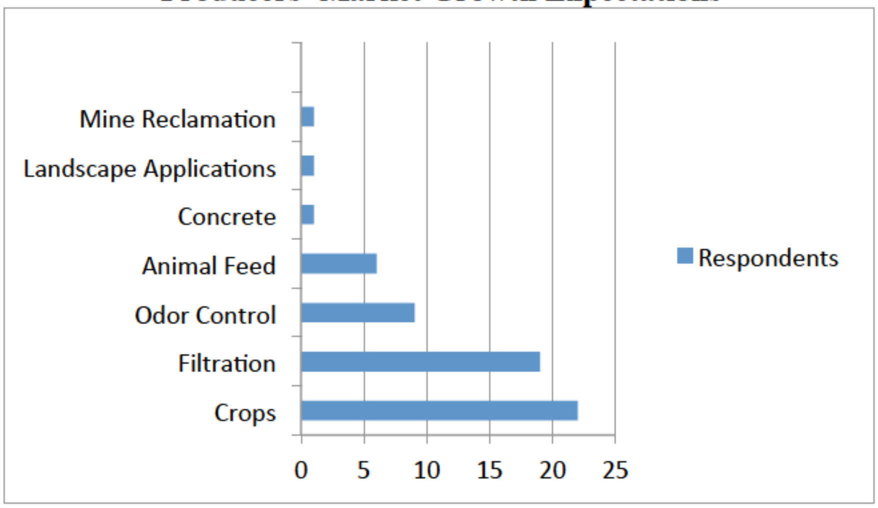
Most producers provide information to customers about their biochar—from analysis results to how-to-use instructions. Only 1 of the large volume producers reported providing no information.

None of the biochar producers—of any size—expect there to be a decrease in demand, with almost 60% of respondents expecting sales to increase more than 10% in the next 5 years. Most of the larger tier producers expect demand to grow modestly to significantly. Only 4 of the 23 upper tier producers anticipate needing to expand capacity to meet growing demand and only three of them expect to have a problem obtaining feedstock. The feedstock sourcing is predominantly woody in nature, but a wide variety of materials are viewed as potential sources, including manures, grasses, ag waste, construction waste, fiber, and food waste.

[8] https://www.omri.org/; https://www.ams.usda.gov/grades-standards/organic-standards; http://www.biochar-international.org/sites/default/files/IBI_Biochar_Standards_V2_0_final_2014.pdf. For more information see also: http://www.dovetailinc.org/report_pdfs/2017/dovetailbiocharpotential0517.pdf

The market segments showing the highest expectations for growth are, in rank order: crops, filtration, odor control and "other," with biochar as an animal feed supplement the most mentioned (Figure 4).

Figure 4.
Producers' Market Growth Expectations



Advertising biochar was reported to be direct, relatively traditional, and unsophisticated (Table 2).

Table 2. Biochar Advertising

Word of mouth	68%
Direct response to inquiries	46%
Google Adwords	2%
Print media	10%
Website and other electronic media	44%
Conference and trade show displays	29%

The top producers report having spent millions on research annually, with the level of support declining proportionately as production levels decreased. The degree of decrease was not linear; however without more specific data, relative percentages and trends cannot be determined.

The survey's last section asked open-ended questions about policy and opportunities for support that provided wide ranging responses. There were many thoughtful suggestions and a few common threads, which will be captured and discussed in the analysis section.

Users Survey Results

The following figures (Figures 5 and 6) show the disparity in volume between the producer and user respondents. As noted above, the users represent less than 1% of the estimated domestic production of biochar.

Figure 5.

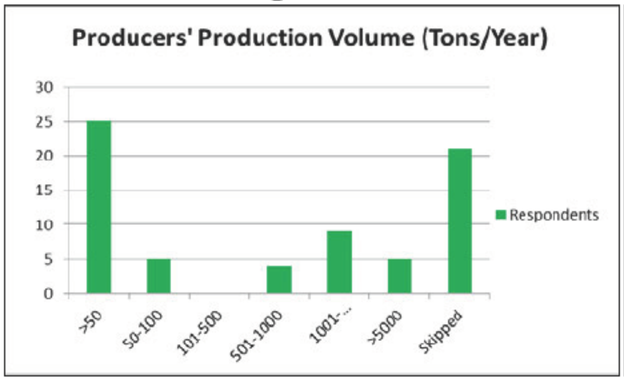
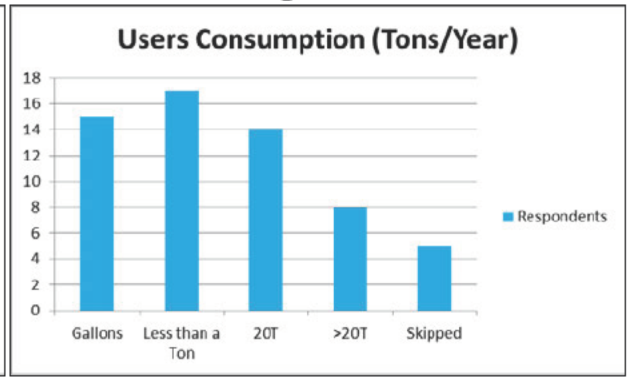


Figure 6.



The breakdown of users was:

- 5 users consuming more than 20 Tons per year of biochar (TPY)
- 10 users consuming between 5 and 20 TPY
- 11 users consuming less than 1 TPY
- 25 users consuming a few gallons per year (at 7.5#/gal.)
- 6 users didn't specify quantity.

Most user respondents classified themselves as gardeners, farmers or landscape contractors. In the larger users, most were resellers. The motivation for using biochar was fairly consistent and multi-faceted, including: modifying soil texture, improving air/water porosity, improving water management, and increasing soil carbon. There was modest motivation to change soil chemistry or modify pH and/or to improve disease resistance.[9]

The majority of respondents (55%) use the biochar dry. 38% use it inoculated and 39% blend it, most commonly with soil and/or other soil amendments.

The biochar users bought the material in the following forms (in rank order) :

1. Fine powder
2. Fine screened chips
3. Coarse chips
4. Pellets
5. Granules or prills
6. Liquid suspension

[9] For more discussion about biochar uses and benefits see the Dovetail Report: *Biochar As An Innovative Wood Product: A Look At Barriers To Realization Of Its Full Potential*; http://www.dovetailinc.org/report_pdfs/2017/dovetailbiocharpotential0517.pdf

As seems reasonable, larger volume users have been in business longer than smaller users, however 49% of all respondents have been using biochar for at least two years and most of the top tiers have over 5 years experience.

Of the 54 respondents, there was a notable increase in current volume used versus expectations for the coming year (Table 3).

Table 3. Biochar Usage Rates

Usage	**Last Year**	**This Year**
Less than a ton	49%	28%
More than a Ton	23%	31%
A Semi-Truckload (20T)	19%	26%
Multiple Truckloads	9%	15%

There seems to be broad satisfaction with suppliers in that 81% of users have not changed from whom they buy; 10% had changed suppliers due to quality issues and 8% due to availability issues.

Organic/OMRI Certification was important to 31% of respondents; IBI to 9%; State-level certification to 15%; and no certification was noted as important by 36%. A total of 92% of respondents said the climate impact of biochar was of importance to them. Only 4 of the 26 upper tier producers (15%) said the climate impact of biochar was unimportant.

Most top tier users get their supply from a 100 to 500 mile shipping distance, but 27% of them experience shipping distances of over 1500 miles. With few exceptions, respondents indicated the fact the biochar is produced locally was an important criteria (94%).

When asked whether they knew or cared from what or how their biochar was made only one respondent answered “no.” Four percent said that information was not disclosed and 85% said they knew the details despite responses to a question about receiving an analysis where only 43% responded “yes”. All the recurrent large volume buyers received analyses of their biochar while only 40% of the truckload volume buyers received analyses.

Reported prices paid for biochar ranged widely depending on the packaging and volume purchased. For the larger scale users the lowest cited cost was $75/ cubic yard (CY), the average price was $129/CY, with $200/CY FOB the most often cited price (or $1600/Ton). [10]

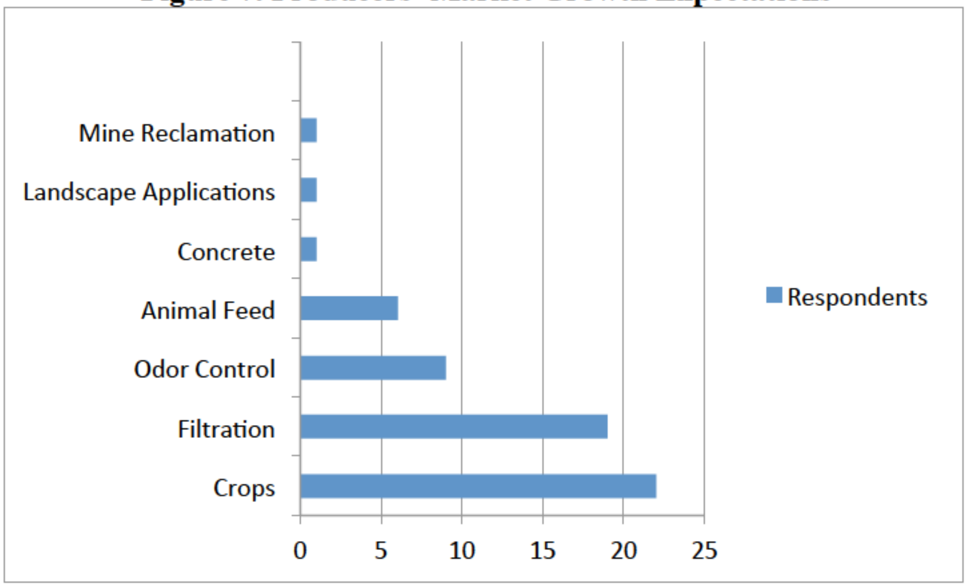
As with the producers, the input offered from open-ended questions will be discussed in the analysis section.

[10] Conversions used: 8CY/ton or 216 CF/ton; 9.25#/CF; 1CY = ~22gallon

Analysis of Producers Survey Data

Two trends stand out: expected growth in production based on optimism about the strength of the marketplace and a desire for more information and support from all categories of resource providers. As shown in Figure 7, producers have market growth expectations in many segments, including crops, water filtration, odor control applications, and animal feed.

Figure 7. Producers' Market Growth Expectations



The responses in growth of year-to-year production were confusing. On one hand, producers expected there would be stable to lower market prices for biochar, which was countered by Users expectations that prices would rise. Producers largely expected there to be geographically widespread availability of feedstocks at affordable prices. However muddy the economic picture is, the attitude that there would be positive movement in biochar sales was widespread with both survey groups.

Responses to questions about how the industry/trade association, public policy, and the USFS specifically can support and grow the market provided particular insight. The most oft cited historic support comes from IBI and USFS Wood Innovation Grants. In response to the question asking which policy or research initiatives have been helpful, five of the 12 largest producers cited collaborative research projects with State and International Research Institutions. No details were offered, but a look at the IBI website provides a sense of the scope and scale of current research efforts.[11] Additionally, IBI offers a bibliography of all known biochar related publications to members; there are currently thousands of citations.

From a policy standpoint, help would come from recognizing biochar as carbon negative (and getting some financial credit for it); as mentioned by almost 25% of the respondents. The second most repeated support need was to certify biochar as an animal feed supplement—by six of the larger producers (23%). Both USDA and FDA were cited as important players in opening that

[11]For collaborating biochar research organizations worldwide: https://biochar-international.org/research/

market. It was noted by a number of respondents that biochar as a feed supplement is allowed in Europe already.[12] In all but 4 EU countries, biochar is an approved animal feed ingredient. Dairy cows are the livestock using this supplement the most.

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There was frustration expressed with EPA regulations by two mid-sized operations, but no specifics were provided as to what actions would help ease their concern.

A number of producers noted the need for stronger definition of biochar "grades" and improved standards[13]. Others made mention of the desire for more support to get the word out to users (the public and farmers specifically) about the benefits of biochar.

Responses to a question about how USBI or a trade association could best support producers were very similar to the question about what policy initiatives would help most: advocacy for carbon credits, education of the public and farmers specifically, marketing, and research leadership.

Two notable actions were suggested for USBI (US Biochar Initiative.) The first is to participate more in long-term research which (hopefully) shows the benefits of biochar in soil and mixed amendment systems. The second notable suggestion was for market research which "compares biochar to existing products (like compost and potting/soil blends) to determine price points and pain points of buyers that use other [soil amendment] products.

In response to a question how the USFS and Federal Agencies could support the biochar industry a number of responses cited they could increase purchasing biochar for forest and mine reclamation. Improved accessibility to, and the increased use of stewardship contracts to provide feedstock was mentioned by a number of producers, while compliments were given to USFS for the use of stewardship contracts by other producers. Streamlined regulations to acquire woody biomass were mentioned by multiple respondents. One insightful respondent suggested a cost/benefit analysis: "Quantify in $ terms the benefits of avoided slash piling burning, irrigation water availability from juniper treatments and thinning." As well as "Economic and enterprise models that help build an investment case for biochar production."

One interesting response was the amount spent on research internally. Three of the five largest firms claim to be spending in excess of $1M/year; 2 currently mid-sized operations report spending similarly, and four others were in the $250K to $500K range. These commitments are impressive and, for a relatively young industry with a relatively small market, can be interpreted as indicative of optimism for stronger demand for biochar products.

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[12] Ithaka Institute presentation (2011) http://vec.vsb.cz/katalog-obrazku/clanek-135/245-schmidt.pdf

[13] This was identified as a high priority during the 2018 USBI Biochar Conference and is discussed in more depth in the "Follow-up Interview…" Section below.

Analysis of Users Survey Data

The users survey provided a snapshot of an optimistic marketplace. Many of the smaller users left comments expressing their interest in learning more about biochar (which was taken to mean interest in technical information), about the broader biochar marketplace, about how to market more effectively to grow their businesses, and for more in-depth information about research results (which could help their understanding and marketing).

One respondent expressed interest in using biochar as a concrete additive and as a component in other building materials (unspecified), which coincidently is being done by one of the large producers, suggesting a potential for collaboration.

Shipping and handling costs were cited by two users as being of more concern than the raw biochar costs even though their shipping distance was less than 500 miles for truckload volumes.

As in the producers' survey responses, users wanted more information about the animal feed and stormwater filtration markets.

Follow-up Interviews and Input from the 2018 USBI Biochar Conference

The 2018 Biochar Conference held in Wilmington, DE on August 21-23 provided an opportunity to gather input from both presentations and follow-up interviews with attendees. There were approximately 300 total attendees at the annual conference. The information gathered reinforced the conclusions drawn from the surveys, but also clarified the issues of most pressing interest.

The topic of Biochar Characterization and "Standards" was of sufficient importance that about 60 people attended a pre-conference session to hear a presentation about making product claims (and the necessity to have a solid relationship to proven facts,) and to discuss how to move forward with establishing the science and the claims. This issue arose repeatedly during the three day conference, in both plenary and concurrent track sessions, and was a frequent topic of informal conversations leading to the conclusion that—as a growing industry—the topic is widely seen as a high priority.

The Conference also provided input on a market segment which was not captured well in the Producer Survey:

> *There was considerable interest among attendees in "appropriately scaled" biochar production. This included potential producers wanting to generate biochar as a primary end product or as a co-product in the generation of thermal and electrical energy. There were a number of attendees interviewed who expressed particular interest in units which could fit into their operations which required portability, simplicity of operation, and capability of producing quality biochar economically.*
>
> *One "technology" which had widespread interest by landowners, smaller scale forest restoration operators, and USFS personnel was a simple open-top, pit-style, sheet-steel*

portable kiln. It enables the operator to quickly produce relatively high-quality biochar on-site, using (and adding value to) woody debris primarily[14].

Most of these potential producers had not completed the survey (or had done so as small users). Therefore this "data point" is one which was not highlighted in the surveys since the focus was on volume users. This "class" of producer could be significant in terms of soil improvement and forest restoration acres treated, just as small-scale intensive agriculture and non-industrial private forest landowners contribute significantly to the production of high-value products in the broader natural resource-based industry.

Other technologies appropriate for smaller scale applications are portable or semi-portable units using gasification processes. Some of these units also provide thermal energy for process use, and one developer planned to test a 25KW Rankine-cycle electrical generator as an option.

A general observation from the Conference's attendees, exhibitors, and presenters is that there is considerable development at the equipment, process, and product levels. The question which hung over these discussions (from the attendees interviewed) was how economical these "appropriately scaled" technologies were actually. A secondary concern was the carbon footprint of these units and whether they would truly sequester more carbon than they generated.

One West Coast Producer noted the "opportune environment" in California, where there's the need for so much active forestry occurring in decent proximity to lots of agricultural customers. When looking at National Forests and ag operations nationwide, there are numerous opportunities for utilizing a variety of feedstocks to make biochar and supply end users locally. Feedlot and poultry houses are good examples of concurrent potential suppliers and users—especially poultry houses in northern climates which require heat and which could use odor control, ammonia reduction for health purposes, and animal feed supplementation, as well as additional income streams. The issues of scale and economics will have to be satisfied by appropriately sized and productive equipment. There is extensive R&D work going into these areas as evidenced by the vendors and suppliers present at the conference.

One plenary presenter[15] noted the rapidly developing interest in soil health. He went on to say that interest has outpaced the understanding of what it takes to operationalize the implementation of improving soils (by which he meant increasing soil carbon.) Biochar is an ideal soil carbon enhancer given its proven benefits of nutrient and water retention and it's longevity in the soil.

The same presenter highlighted his perspective that a major benefit of biochar-in-soil is as a home for the soil microbial ecosystem. Biochar provides the habitat and the inoculation process

[14] For detailed descriptions, see the Conference presentations: https://www.dropbox.com/sh/bib7loivcofsbue/AACMb3ywhS1UghJqTffHbNDda/Commercial/Session%202A%20-%20Commercial?dl=0&preview=2.1.3+Forest+Restoration+Using+Simple+Kilns+Darren+McAvoy.pdf&subfolder_nav_tracking=1 and https://www.dropbox.com/sh/bib7loivcofsbue/AACOQCWxuYKZUklhZXdQD7_Xa/Agriculture/Session%201A%20-%20Agriculture?dl=0&preview=1.1.2+Biochar+for+Small+Woodland+Owners+Kelpie+Wilson.pdf&subfolder_nav_tracking=1

[15] https://www.dropbox.com/sh/bib7loivcofsbue/AACml7h0fW6k_nMTM9YQlOfra/Main%20Stage/Keynote%20Speaker?dl=0&preview=Montgomery+Biochar+2018.pdf&subfolder_nav_tracking=1

populates those spaces. What was not said overtly is that the quality of the biochar is crucial to optimizing the habitat, and that the inoculation process is important, but has to be designed appropriately for the application.

Another attendee noted that without a carbon credit market, the industry is being driven to focus on educating farmers and stormwater managers about the other benefits of biochar. What would seriously advance those marketing efforts is verification of biochar's sequestration capability because (as was seen in the User survey responses) even without economic carbon credits, sequestering carbon is an important criteria for many buyers.

One high profile user—who exhaustively sought a consistent product for their use—advised the industry attendees to "Test your product." The eventual supplier to that user reinforced that message by saying, "Know what your biochar will do. Test your biochar." In a panel, it was noted that, "So many research projects have used poor [untested] biochar that it's done significant damage to the industry's credibility."

In the closing session, Tom Miles, USBI Chair and a team member of this project, referring to this survey noted the general optimism of the industry and his personal observation that the sophistication of the producers is steadily increasing. He counseled the attendees to understand what their customers want as opposed to offering what they could produce. His closing admonition was to "set a high bar for quality."

One comment made by numerous presenters, which coincides with survey input, is to highlight successes (as part of the education and marketing efforts). Individual producers, as well as the wider producers and users have many stories of successful applications and experiences which need to be compiled, organized, and shared.

Conclusions and Next Steps

The two surveys are complementary in their results and reinforced by the follow-up interviews and the tenor of the Biochar Conference. Both producers and users see a growing demand. There are different expectations in price points between the two groups, which will be worked out over time as production is balanced with usage.

The new market segment of biochar as an animal feed supplement is of considerable interest and its potential could have a significant impact on both producers and resellers. Resellers may see less opportunity since volume sales seem to be provided mostly by producers; however, a value added opportunity may exist for resellers to produce a branded or customized end-product, which producers could be reluctant to take on. More information on this market (current European experience, domestic customer interest, price points, and value added opportunities) is needed to better predict how significant it could be. There also needs to be a concerted effort to collect and share success stories about biochar uses and applications.

There was a difference between the form of the biochar being provided by producers and the form being purchased by the users. This knowledge may be useful to producers in aligning better with buyers of their finished product. Future research should explore this facet more closely.

While the surveys were technologically blind, from conference interviews, the issue of technology was one of concern to many interested producers, most of whom were looking for a cost-neutral to marginally profitable way to generate biochar. More demonstrations, data, and analysis are needed to quantify operations of all sizes and technologies. Identifying the most "important or promising" technologies could provide the priorities for further research and analysis.

Biochar as a confirmed carbon-sequestering product was expected to have the greatest potential to enhance its demand. However, it's an unlikely driver in the near term without a solid scientific validation (and/or legislation). There are a wide variety of production technologies and, therefore, a wide range of carbon balances to consider. This variability complicates the certification of carbon sequestration capability and considerable collaboration, funding, and effort will be necessary to establish a credible calculation schema. Political considerations also come into play considerably in this process, as there are already a number of skeptical organizations actively questioning the entire system of woody biomass production and conversion. Collaborating in the biomass energy producer's efforts to quell the skepticism and quantify the potential could be a cost effective strategy.

The Bottom Line

Both biochar producers and users see the need for more attention to the qualities and characteristics of the end product. This message became the mantra for the Biochar Conference which echoed input from the surveys. Further steps toward widely accepted standards are recognized as vitally important and a strategy to develop, disseminate, and implement those standards is an industry priority to allow the market to grow and the industry to mature responsibly.

Biochar producers and users also see the need for much higher profile public and customer education—in support of biochar as a desirable and sought after product. These two objectives are parts of a holistic marketing initiative and have become a high priority.

The third leg of a successful marketing strategy is to validate scientifically any claims to be made about biochar's application benefits. For instance, increased water retention has been a consistently observed phenomenon in research and can easily be claimed. Biochar's carbon sequestration capability is currently under-proven and needs further effort.

For future information on this project check the USBI website: http://biochar-us.org/news/us-biochar-market-survey-0 or visit the Dovetail Partners Report website: http://www.dovetailinc.org/reports.

Special thanks to the Ithaka Institute for use of the image on the coverpage.

Appendix: Survey Questions

Biochar Producer Survey

This survey is underwritten by the US Forest Service to learn more about the biochar industry and its potential to use woody biomass, particularly from National Forests. The individual inputs of this survey will remain confidential and only the aggregated data will be released or used for further analysis. The project team includes USBI and IBI representatives in collaboration with Dovetail Partners, Inc., a non-profit dedicated to the analysis of natural resource and land use issues. Thanks for taking the time to share your expertise.

1. Are you a biochar producer or re-seller? (For the purpose of this survey, a producer makes biochar; a reseller buys biochar for re-sale or as a feedstock for other products.)

    Producer
    Reseller

2. How would you categorize your biochar production?

    Primary Product
    Co-Product of Energy
    Co-Product of Electrical power
    Co-Product of Waste disposal

3. What is your annual production of biochar? (Tons per Year)

    <50
    50-100
    101-500
    501-1000
    1001-5000
    >5000

4. Where do your feedstocks come from? (Check all that apply.)

    Wood Waste from Federally controlled Lands (National Forests, BLM)
    Wood Waste from State controlled Lands
    Wood Waste from Private lands
    As Forest residue
    As Mill residue
    As Urban Waste
    Dairy Manures
    Poultry Manures
    Hog Manures
    Crop Residues
    Sewage Sludge
    Other (please specify)

5. (For resellers) What is your annual purchase of biochar? (Tons per Year)
<50
50-100
101-500
501-1000
1001-5000
>5000
not a reseller

6. To what uses does your biochar go? (Check all that apply.)
Garden
Horticulture, specialty crops
Field Crops
Orchard or tree crops
Turf
Landscaping
Drainage, filtration
Odor control
To Re-sellers; don't know end uses
Other (please specify)

7. Do you make biochar specifically for certain applications?
No
Garden
Horticulture, specialty crops
Field Crops
Orchard or tree crops
Turf
Landscaping
Drainage, filtration
Odor control
To Re-sellers; don't know end uses
Other (please specify)

8. Do you process the biochar after production? (Check all that apply.)
No; sold as is
Inoculated or "Charged"
Screened or sized
Blended with other amendments (e.g. compost)
Activated (e.g. steamed or chemical)
Agglomerated or pelletized
Other (please specify)

9. Please Rank on a dry weight basis in what form your biochar is sold/bought?
   - Fine powder
   - Fine screened chips
   - Coarse chips
   - Pellets
   - Granules or prills
   - Liquid suspension

10. How long have you been producing or selling biochar commercially?
   - <1 year
   - > 1 <2 years
   - > 2 < 5 years
   - > 5 years

11. What certifications do you have or use?
   - Organic/OMRI
   - State Registration
   - IBI
   - None
   - Other (please specify)
   - Locally: < 10
   - Regionally: <500 miles
   - More than 1500 miles
   - Internationally

12. What percentage of your biochar is shipped:

13. If you ship internationally, to what countries?

14. Do customers ask whether the biochar is produced locally?
   - Often
   - Occasionally
   - Rarely
   - Never

15. What kind of information do you provide to your customers?

   - What your biochar is made from and how it is made
   - Lab analysis
   - How to use it (as in how much and how to apply)
   - Extensive discussion to match analysis to application
   - None

16. Rank how you sell your biochar:
   - retail package
   - bulk retail or wholesale (i.e. pallet loads)
   - bulk packaged (like a Supersack)
   - bulk (truckload, rail car, barge)

17. Do you foresee the price of biochar changing in the short term?
    No, it will be stable for the next few years.
    Yes, it will probably drop as more producers come on line.
    Yes, we think it may increase for different types of end users.

18. Do you expect sales for your biochar to change in the 1- 5 year?
    Yes increase somewhat (~10%)
    Yes increase a lot (>10%)
    Stay the same
    Depends on many factors
    Decrease

19. Do you anticipate needing to expand capacity to meet demand?
    Yes
    No

20. Do you have adequate feedstock supply to meet increased demand?
    Yes
    No

21. Do you expect obtaining additional feedstock to be a problem?
    Yes
    No

22. From what sources do you expect to get additional feedstock?

23. Please rank the market segment growth you expect over the next year:
    Crops
    Filtration
    Odor control
    Other (Please specify in next question)

24. If "Other", please elaborate

25. What market segment growth do you expect over the next 5 years:
    Crops
    Filtration
    Odor control
    Other (please specify)

26. How do you market/sell/promote your biochar?
Word of mouth
Direct response to inquiries
Google Adwords
Print media
Website and other electronic media
Conference and trade show displays
Other (please specify)

27. What biochar-related policy or research initiatives have been helpful to your enterprise? (For example: Local or Regional initiatives, Extension or NRCS events, Wood Innovation Grants)

28. What policy initiatives would be most helpful to your business and/or to the biochar industry?

29. Roughly, how much do you spend on research internally?

30. What initiatives by USBI or a trade association would be most beneficial to your business and/or the biochar industry as a whole?

31. How can the US Forest Service or other land managers assist your biochar production?

32. In what region are you located?
New England (ME to NY)
Mid Atlantic (PA to SC)
Deep South (GA to LA)
West Coast (WA to CA)
Plains States (ND to OK)
Rocky Mtn States (ID , MT, WY, CO)
Lake States (MN, MI, WI)
Central US (IA, MO, AR, IL, IN, OH, TN, KY, WV)
TX
AK, HI
CANADA

33. Can we follow up with you?
Yes (Space for contact info below)
Prefer not

Thank you for your time and participation. We will provide results of this survey directly, as well as further analyses and reports, if you provide contact info below. We will ONLY use the contact information for sharing this information unless you give permission for follow-up. Alternately you can look for announcements by USBI, IBI, and Dovetail Partners. Again, thanks for your support.

Biochar User Survey

This survey is underwritten by the US Forest Service to learn more about the biochar market and the potential to use woody biomass to make biochar, particularly from National Forests. Individual inputs to this survey will remain confidential and only the aggregated data will be released or used for further analysis. The project team includes USBI and IBI representatives in collaboration with Dovetail Partners, Inc., a non-profit dedicated to the analysis of natural resource and land use issues. Thank you for taking the time to share your input and expertise.

1. How would you categorize yourself from a biochar user/buyer perspective? (Check all that apply.)

Gardener
Farmer
Landscape- contractor
Golf course manager
Remediation specialist
Filtration specialist
Stormwater
Industrial process
Odor
Ag waste
Green house Grower
Biochar reseller (please also take our producer survey)
Other (please elaborate)

2. If you use biochar for soil purposes, please rank the reasons:

To modify soil texture
To change soil chemistry, pH modification
To improve Air/water porosity
To improve water management
To improve disease resistance
Increase Soil carbon
Other (please elaborate)

3. How do you use biochar? (Check all that apply.)

Dry
Inoculated
Blended
With other soil amendments
Specifically, with Compost
Specifically, with Peat or coconut fiber
As a granulated fertilizer
As a liquid for injection or spraying

4. What is your preferred form of biochar?
    Fine powder
    Fine screened chips
    Coarse chips
    Pellets
    Granules or prills
    Liquid suspension

5. How long have you been using biochar?
    <1 year
    > 1 <2 years
    > 2 < 5 years
    > 5 years – about 5 years

6. Approximately how much biochar have you used to date?
    Small amounts: several gallons
    Medium: under a ton
    Large: truck load
    Recurring large buyer

7. Approximately how much biochar did you use last year?
    Small amounts: several gallons
    Medium: under a ton
    Large: truck load
    Multiple truck loads

8. How much biochar do you expect to use during the next year?
    Small amounts: several gallons
    Medium: under a ton
    Large: truck load
    Multiple truck loads

9. Have you switched suppliers due to availability or quality issues?
    Yes, due to availability issues
    Yes, due to quality issues
    No, I generally buy from the same vendor.

10. What certifications or registrations are important to you?
    None
    Organic/OMRI
    State Registration
    IBI
    Other (please specify)

11. How would you rate your level of knowledge about biochar?
    Expert: keep up with research and attend webinars and conferences
    Knowledgeable: am fairly conversant with state of the art and applications
    Know enough for my own use.
    Novice: Just getting started and have lots to learn.

12. How far is your biochar shipped?
    Locally: <100
    Regionally: <500 miles
    Cross country: i.e., more than 1500 miles
    Internationally
    Which country/countries?

13. Is locally produced biochar preferable to you?
    Yes
    No

14. Do you know or care what your biochar is made from and how it is made?
    I know what it is made from but not how (i.e. what technology or process parameters)
    I know both how and from what it is made.
    This information is not disclosed.
    This information is not important to me.

15. Is the climate impact of biochar important to you?
    Yes, very important.
    Somewhat important
    Not really important

16. Do you receive an analysis of the biochar you purchase?
    Yes
    No

17. Please indicate what you're paying for the biochar? (If it's a blended product, please include the biochar component percentage?)

18. If the current cost of biochar is a barrier, at what price point would you consider purchasing large(r) amounts of biochar? (unblended biochar only)
    $50/cubic yard (i.e. ~202 gallons)
    $100/cubic yard
    $500/ton
    $1000/ton
    Other

19. What additional information would you like to know about biochar?

20. Is your reason for using biochar:

Personal (a non-income-producing use, like a garden, orchard, or houseplants)
Commercial (such as for crops, landscaping, or creating commercial products)
Mitigation (solving a problem, but not necessarily generating revenue)

21. In what region are you located?

New England (ME to NY)
Mid Atlantic (PA to SC)
Deep South (GA to LA)
West Coast (WA to CA)
Plains States (ND to OK)
Rocky Mtn States (ID , MT, WY, CO)
Lake States (MN, MI, WI)
Central US (IA, MO, AR, IL, IN, OH, TN, KY, WV)
TX
AK, HI
CANADA

22. Can we follow up with you?

Yes (space for contact info below)
Prefer not.

Thank you for your time and participation. We will provide results of this survey directly, as well as further analyses and reports, if you provide contact info below. We will ONLY use the contact information for sharing this information unless you give permission for follow-up. Alternately you can look for announcements by USBI, IBI, and Dovetail Partners. Again, thanks for your support.

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Dovetail Partners, Inc. - A Trusted Source of Environmental Information

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SILVER JUBILEE BTH 1987-2012

BTH

BANGALORE TEST HOUSE

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OHSAS 18001 : 2007 & ISO 9001 : 2008
JAS-ANZ
Cert. No. RQ91/JA/1111
Cert. No.: RO91/JA/IC/1111

TEST REPORT

Report No. : ED/2015/07/0600	**Report Date** : 30/07/2015
Issued to : **Tide Technocrats Pvt Ltd (TTPL)** **#768 (1st Floor), 14th Cross, 33rd Main,** **J.P.Nagar, 1st Phase,** **BANGALORE - 78.**	**Customer Reference:** Quotation, Date: 17/07/2015 **Date of Receipt** : 22/07/2015 **Date of Start of Test** : 23/07/2015 **Date of Completion of Test** : 30/07/2015
Sample Nature/ Name : Biochar	**Job Order No.** : ED/2015/07/0600 **Sample Particulars** : Biochar
Sample Condition : Satisfactory	

SL. No.	PARAMETERS	Results	Test Method
	Microbiology Tests:		
1	Salmonella / 25g	Absent	IS: 5887 (Part III) 1976
2	E. coli / 25g	Absent	IS: 5887 (Part I) 1976
3	Total Coliform Organisms /g	Absent	IS: 5401 (Part I) 2002
4	Psuedomonas /25g	Absent	Annex D of IS: 13428-2005

ANALYST

AUTHORIZED SIGNATORY

THE STATE of ALASKA
GOVERNOR BILL WALKER

Department of Environmental Conservation

DIVISION OF ENVIRONMENTAL HEALTH
Solid Waste Program

610 University Avenue
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June 19, 2017

via electronic mail to: jen@re-locatellc.com

Jennifer Marlow
Re-Locate LLC
8221 Prospect Place
Anchorage, AK 99507

Re: Kivalina Biochar Reactor, Letter of Non-objection

Dear Ms. Marlow:

The Alaska Department of Environmental Conservation (ADEC) Solid Waste Program understands that Re-Locate LLC intends to install in Kivalina a Biomass Controls biogenic processor unit to convert human septage into biochar. Some of the biochar will be utilized as an odor control medium within the biogenic processor; biochar that isn't needed for that purpose will be disposed in the Kivalina landfill. Since odor control is a requirement of the solid waste regulations, ADEC has no objection to the proposed re-use of the biochar for odor control in the biogenic processor.

According to the information provided to ADEC, the biogenic processor is capable of processing 400 pounds of sewage solids each day. Since this is less than the current permit threshold, under current solid waste regulations, the unit does not require a treatment facility permit. However, please note that a permit may be required if proposed changes to the solid waste regulations are implemented. ADEC will notify you if/when a permit is needed.

Based on analytical results for a similar processing unit in India, ADEC expects that the biochar will have a significantly reduced concentration of pathogens. As such, disposing the biochar in the landfill will pose a much lower risk to the community than disposal of the untreated material. On that basis, ADEC has no objection to disposing of the biochar in the unpermitted Kivalina landfill. However, ADEC understands that pathogen concentrations in the biochar will be confirmed by analytical testing once the Kivalina unit is operational.

If you have any questions about this letter, please feel free to contact me by telephone at 907-451-2135 or by email at doug.buteyn@alaska.gov.

Sincerely,

Douglas Buteyn

Douglas Buteyn
Northern/Southeastern Regional Program Manager
Solid Waste Program

\\ln-svrfile\groups\EH\Eh-Solid Waste\Communities\KIVALINA\Biochar-2017\2017-06-19 Non-Objection-Letter.docx

Contaminant Concentrations in Traditional Fuels:
Tables for Comparison

November 29, 2011

= =

In an effort to provide additional information and data to the regulated community concerning the concentrations of contaminants that may be found in traditional fuels, the following tables present summary statistics for contaminant concentrations in common traditional fuels. Members of the regulated community may find the data presented here useful when comparing contaminants in their non-hazardous secondary materials (NHSMs) to contaminants in the appropriate traditional fuels.[1]

- Use of these tables is not required to demonstrate compliance with the contaminant legitimacy criterion, and the existence of these tables does not preclude the use of other data sources. EPA has organized and presented this data as a service to assist NHSM processors and combustors in making contaminant comparisons. The Agency will periodically update these tables as additional data become available.

- The following three tables cite contaminant data from both the scientific literature and EPA databases for coal, wood/biomass, and fuel oil. NHSMs burned in combustion units are most often substituted for one of these three traditional fuels.

- The two referenced EPA databases, both compiled by the Agency's Office of Air Quality Planning and Standards (OAQPS), together contain approximately 32,000 records of contaminant analyses performed on coal (~17,000), wood/biomass (~12,000), or fuel oil (~3,000) samples prior to combustion. Summary statistics from this comprehensive dataset are displayed separately from other data sources, but persons using these tables to make contaminant comparisons are not constrained to one column or one data source for the appropriate traditional fuel.

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[1] All data presented in this document are for individual contaminants for which EPA has information. Please note that targeted revisions to the rule are under development, with the goals of both clarifying the 40 CFR Part 241 requirements and facilitating implementation of the rule as EPA originally intended. EPA is considering including a discussion of contaminant groups (e.g., VOC), an alternate option for contaminant comparisons involving hazardous air pollutant compounds that NHSM processors and combustors may want to consider.

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Table 1: Contaminant Concentrations in Coal[1]

Contaminant	Units	Literature Sources	OAQPS Databases[2]		
		Range	Range	Average[3]	Non-Detect Rate
Metal elements - dry basis					
Antimony (Sb)	ppm	0.5 - 10[4]	ND - 6.9	1.7	25 %
Arsenic (As)	ppm	0.5 - 80[4]	ND - 174	8.2	8 %
Beryllium (Be)	ppm	0.1 - 15[4]	ND - 206	1.9	12 %
Cadmium (Cd)	ppm	0.1 - 3[4]	ND - 19	0.6	38 %
Chromium (Cr)	ppm	0.5 - 60[4]	ND - 168	13.4	1 %
Cobalt (Co)	ppm	0.5 - 30[4]	ND - 25.2	6.9	8 %
Lead (Pb)	ppm	2 - 80[4]	ND - 148	8.7	5 %
Manganese (Mn)	ppm	5 - 300[4]	ND - 512	26.2	<1 %
Mercury (Hg)	ppm	0.02 - 1[4]	ND - 3.1	0.09	5 %
Nickel (Ni)	ppm	0.5 - 50[4]	ND - 730	21.5	<1 %
Selenium (Se)	ppm	0.2 - 10[4]	ND - 74.3	3.4	22 %
Non-metal elements - dry basis					
Chlorine (Cl)	ppm	--	ND - 9,080	992	4 %
Fluorine (F)	ppm	--	ND - 178	64.0	9 %
Nitrogen (N)	ppm	--	13600 - 54000	15090	0 %
Sulfur (S)	ppm	--	740 - 61300	13580	0 %
Hazardous air pollutant (HAP) compounds[5]					
Benzene	ppm	ND - 38[6]	--	--	--
Ethyl benzene	ppm	0.7 - 5.4[6]	--	--	--
16-PAH	ppm	6 - 253[7]	--	--	--
PAH (52 extractable)	ppm	14 - 2090[7]	--	--	--
Styrene	ppm	1.0 - 26[6]	--	--	--
Toluene	ppm	8.6 - 56[6]	--	--	--
Xylenes	ppm	4.0 - 28[6]	--	--	--

Sources and Notes:

1. This table includes data for anthracite, bituminous, sub-bituminous, and lignite coal.
2. USEPA, Office of Air Quality Planning and Standards (2011a & 2011b).
3. Averages are weighted averages of individual facilities responding to the OAQPS survey. Averages only include samples above detection limits.
4. Clarke and Sloss (1992).
5. HAPs listed here include only those HAPs with available data. These are not the only HAP compounds considered contaminants.
6. Fernandez-Martinez (2000).
7. Laumann, et al. (2011).

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Table 2: Contaminant Concentrations in Wood & Biomass Materials[1]

Contaminant	Units	Literature Sources	OAQPS Databases[2]		
		Range	Range	Average[3]	Non-Detect Rate
Metal elements — dry basis					
Antimony (Sb)	ppm	ND - 26[4]	ND - 6.0	0.9	45 %
Arsenic (As)	ppm	ND - 6.8[4]	ND - 298	6.3	57 %
Beryllium (Be)	ppm	--	ND - 10	0.3	69 %
Cadmium (Cd)	ppm	ND - 3[4]	ND - 17	0.6	32 %
Chromium (Cr)	ppm	ND - 130[4]	ND - 340	5.9	14 %
Cobalt (Co)	ppm	ND - 24[4]	ND - 213	6.5	23 %
Lead (Pb)	ppm	ND - 340[4]	ND - 229	4.5	28 %
Manganese (Mn)	ppm	7.9 - 840[4]	ND - 15800	302	<1 %
Mercury (Hg)	ppm	ND - 0.2[4]	ND - 1.1	0.03	22 %
Nickel (Ni)	ppm	ND - 540[4]	ND - 175	2.8	17 %
Selenium (Se)	ppm	ND - 2[4]	ND - 9.0	1.1	69 %
Non-metal elements — dry basis					
Chlorine (Cl)	ppm	ND - 2600[4]	ND - 5400	259	5 %
Fluorine (F)	ppm	ND - 300[4]	ND - 128	32.4	43 %
Nitrogen (N)	ppm	200 - 39500[4,5]	2200 - 4600[5]	3460	0 %
Sulfur (S)	ppm	ND - 8700[4]	ND - 6100	704	5 %
Hazardous air pollutant (HAP) compounds[6]					
Formaldehyde	ppm	1.6 - 27[7]	--	--	--

Sources and Notes:

1. This table includes data for untreated wood and biomass, including bark, bagasse, hog fuel, and agricultural plant residues.
2. USEPA, Office of Air Quality Planning and Standards (2011a & 2011b).
3. Averages are weighted averages of individual facilities responding to the OAQPS survey. Averages only include samples above detection limits.
4. Energy Research Centre for the Netherlands, Phyllis Biomass database. http://www.ecn.nl/phyllis.
5. OAQPS nitrogen range based on 20 samples from two facilities, whereas Phyllis biomass database nitrogen range reflects the results of 394 studies.
6. HAPs listed here include only those HAPs with available data. These are not the only HAP compounds considered contaminants.
7. T. Hunt (2011).

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Table 3: Contaminant Concentrations in Fuel Oils[1]

Contaminant	Units	Literature Sources	OAQPS Databases[2]		
		Range	Range	Average[3]	Non-Detect Rate
Metal elements - dry basis					
Antimony (Sb)	ppm	ND - 15.7[4]	ND - 3.8	3.5	97 %
Arsenic (As)	ppm	--	ND - 13	1.3	72 %
Beryllium (Be)	ppm	--	ND - 19	2.3	73 %
Cadmium (Cd)	ppm	--	ND - 1.4	0.4	75 %
Chromium (Cr)	ppm	--	ND - 37	3.7	65 %
Cobalt (Co)	ppm	--	ND - 8.5	1.1	84 %
Lead (Pb)	ppm	ND - 56.8[4]	ND - 52	4.3	46 %
Manganese (Mn)	ppm	--	ND - 3200	118	49 %
Mercury (Hg)	ppm	--	ND - 0.2	0.02	74 %
Nickel (Ni)	ppm	ND - 50.2[4]	ND - 270	24.1	39 %
Selenium (Se)	ppm	--	ND - 4	0.8	74 %
Non-metal elements - dry basis					
Chlorine (Cl)	ppm	--	ND - 1260	133	35 %
Fluorine (F)	ppm	--	ND - 14[5]	8.5	80 %
Nitrogen (N)	ppm	42 - 8950[4]	2000 - 3000[6]	2250	0 %
Sulfur (S)	ppm	--	ND - 57000	8280	9 %
Hazardous air pollutant (HAP) compounds[7]					
Benzene	ppm	ND - 75[4]	--	--	--
Biphenyl	ppm	1000 - 1200[8]	--	--	--
Cumene	ppm	6000 - 8600[9]	--	--	--
Ethyl benzene	ppm	22 - 1270[8]	--	--	--
Hexane	ppm	50 - 10000[8]	--	--	--
Naphthalene	ppm	ND - 7330[8]	--	--	--
Total PAH	ppm	3900 - 54700[4]	--	--	--
Phenol	ppm	ND - 7700[8]	--	--	--
Styrene	ppm	ND - 320[8]	--	--	--
Toluene	ppm	ND - 380[4]	--	--	--
Xylenes	ppm	ND - 3100[8]	--	--	--

Sources and Notes:

1. This table includes data for fuel oils 1-6, including distillate, residual, kerosene, diesel, and other petroleum based oils. It does not include data for gasoline or unrefined crude oil.
2. USEPA, Office of Air Quality Planning and Standards (2011a & 2011b).
3. Averages are weighted averages of individual facilities responding to the OAQPS survey. Averages only include samples above detection limits.
4. U.S. EPA (1999), Appendix B.
5. OAQPS fluorine range based on a limited dataset (59 samples from only five facilities). Detection limits for non-detect results ranged from 19 to 300 ppm, all higher than the maximum recorded value of 14 ppm.
6. OAQPS nitrogen range based on a limited dataset (12 samples from only one facility).
7. HAPs listed here include only those HAPs with available data. These are not the only HAP compounds considered contaminants.
8. USEPA (2000).
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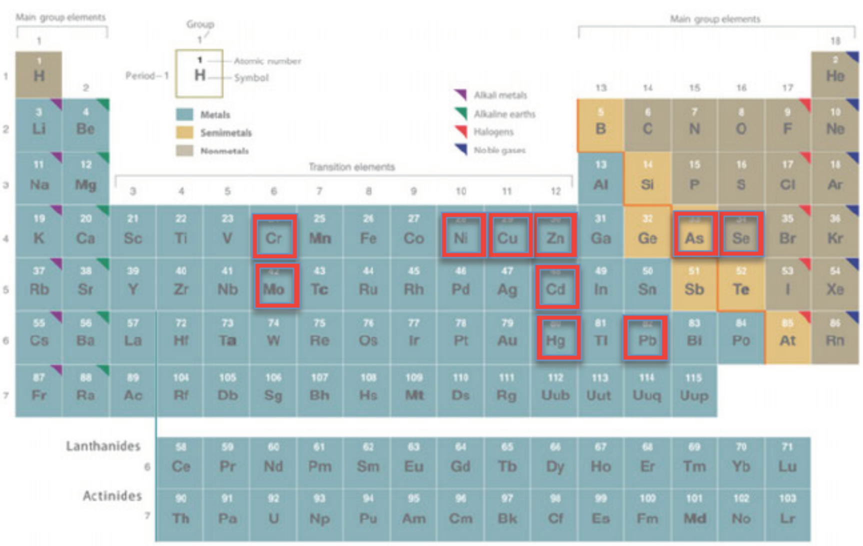
Cooperatively promoting the environmentally sound recycling of biosolids and other residuals

Information Update:
Metals in Biosolids, Other Soil Amendments, & Fertilizers
August 28, 2015

What about the heavy metals in biosolids?

Biosolids contain traces of basic elements, such as heavy metals, as well as other trace contaminants. Trace elements, including heavy metals, occur naturally in soils, fertilizers, other soil amendments, and elsewhere in varying amounts. Living things in our environment, from trees and grasses to humans, contain heavy metals and trace contaminants. Some metals, in the right quantity, are vital nutrients for plants and animals (e.g. copper and zinc). However, high concentrations of some elements and other contaminants can pose a risk to public health or the environment. The concern is not that heavy metals and other contaminants exist in fertilizers, manures and biosolids, but at what levels they exist.

Decades of research and risk assessment have led to regulatory standards for elements and other contaminants that potentially pose risk in the environment. In 1993, in the federal biosolids regulation 40 CFR Part 503, the U. S. EPA established numerical concentration limits in land-applied biosolids for ten elements (the limit for chromium was later withdrawn). Most states have done additional risk assessments and established identical or similar numerical limits for the same elements and, in some states, additional contaminants of potential concern. In addition, risk assessments have been conducted on hundreds of other contaminants and elements of potential concern in biosolids, but regulatory limits have been set only for those elements and other contaminants that have been found in biosolids at high enough levels to warrant concern and limitation. Just because there is no regulatory limit for an element or other contaminant does not mean it has not been studied; it likely has been – and been found to not pose risk. The current regulatory limits ensure that high levels of potentially harmful elements and other contaminants will not occur in biosolids that are applied to soils.



Periodic Table of the Elements. Regulated elements (including "heavy metals," semimetals or metalloids, etc.) are outlined in red.

Today, more than twenty years after the promulgation of the EPA Part 503 rule, the levels of trace elements of true concern (e.g. the heavy

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metals cadmium, lead, and mercury) in biosolids are low. Wastewater treatment facilities impose restrictions on what can be discharged to their sewers, so that dangerous materials do not threaten the treatment facilities' biological processes and the quality of the cleaned water and biosolids.

Today, biosolids are widely sold as valuable soil amendments and fertilizers. All such products are routinely tested for the regulated elements (heavy metals) of concern. The operators who produce and test the biosolids are required to certify that the biosolids have been treated and tested and meet regulatory standards. Improper certification can lead to large fines and jail time. Product quality and safety are ensured.

What are the levels of heavy metals of concern in biosolids compared to other soil amendments?

Trace elements (including heavy metals) of potential concern in modern biosolids have been reduced to low, safe concentrations. Data compiled from the scientific literature by NEBRA in 2015 provides comparisons between biosolids and other soil amendments and fertilizers (Table 1; see also the associated NEBRA spreadsheet "Metals & Other Contaminants in Biosolids, Other Soil Amendments, & Fertilizers," available at http://www.nebiosolids.org/resources/#/heavy-metals-trace-elements/). They indicate that, while biosolids often have somewhat higher concentrations of some elements than average agricultural soils, animal manures, and many fertilizers, the differences are not large. For some elements, the concentrations in manures or specialty fertilizers – and even in some natural soils – are greater than in average biosolids products.

Keeping contaminants out of wastewater

A very clear trend in biosolids quality can be seen in the concentrations of regulated elements in land-applied sewage sludges and biosolids over time, as industrial pretreatment and source reduction has kept these contaminants of concern out of wastewater. The result has been a dramatic reduction in trace element levels over the past 40 years, as shown in this WHO 2001 compilation and 2009 U. S. EPA data:

Trends in metal concentrations of wastewater solids (sewage sludge) produced by wastewater treatment plants in the U. S., with comparison to U. S. EPA limits for low-metals biosolids

Year	As	Cd	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn
1976[1]	-	110	2620	1210	1360	-	-	320	-	2790
1979[2]	7	69	429	602	369	3	18	135	7	1594
1987[3]	12	26	430	711	308	3	-	167	6	1540
1988[4]	10	7	119	741	134	5	9	43	5	1202
1996[5]	12	6	103	506	111	2	15	57	6	830
2009[6]	6.9	2.6	80.2	553	76.2	1.2	15.3	48.3	7.0	970
EPA low metals limit (503, Table 3)	41	39	NS[7]	1500	300	17	NS[7]	420	36	2800

[1 – 5] World Health Organization (WHO) 2001 compilation, which cites the following data sources: [1] 150 treatment plants in Northeast and North Central states (Sommers, 1977); [2] USEPA 40 city survey (U.S. Environmental Protection Agency, 1989); [3] 64 treatment plants across the U. S. (Pietz et al., 1998); [4] USEPA national sewage sludge survey of 200 treatment plants (U. S. Environmental Protection Agency, 1990); and [5] >200 treatment plants throughout USA (Pietz et al., 1998). [7] U. S. EPA targeted national sewage sludge survey, 2009.

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What is the chance that any particular load of biosolids will have contaminants in excess of the regulatory limit?

Tests of biosolids show that there is some variability in the concentrations of contaminants – including heavy metals – from one biosolids to another and from the same biosolids material over time. However, these variabilities are not large, because biosolids are formed through a continuous process – wastewater treatment – that involves a lot of mixing. In addition, biosolids are further treated and mixed over several days, so that momentary higher or lower concentrations coming into a wastewater treatment facility are evened out.

In the 2000s, the New Hampshire Department of Environmental Services compiled hundreds of test results from 23 different biosolids produced at wastewater treatment facilities of all sizes around the state. UNH Professor Thomas Ballestero conducted statistical analyses on the test results and, for each contaminant, determined the mathematical probability of any test result ever exceeding the state's conservative regulatory or guidance limit. For every contaminant, the probability was low: on the order of 0 to 5%. Which means that NH biosolids are safe for land application. And especially safe, because the NH limits are lower – more strict – than the risk-based federal limits.

The contribution of trace contaminants from any soil amendment or fertilizer depends on the rate of application and the properties of the amendment and soil.

When considering the impacts and potential risks associated with applying trace elements (e.g. heavy metals) to soils, it is important to remember:

- Elements occur naturally in soils.
- Elements added to soils will remain in the environment; they do not break down. However, depending on their chemistry and that of the soil, some elements may move from soil to groundwater, surface water, the atmosphere, or into biological organisms (food chain).
- Heavy metals and semimetals tend to bind strongly in biosolids and in soils (especially soils with organic matter) at the mid-range pH of agricultural sites; thus, they are usually considered to be permanent additions to the soil and are not likely to impact plants or water. In comparison, metals in mineral fertilizers are more mobile in soil, especially soil with little organic matter. Biosolids bring binding capacity with them; indeed, biosolids are sometimes used to reduce the availability – through binding - of metals in soils where metals are at unusually high concentrations (e.g. lead in urban soil).

The total mass of any particular trace element applied depends on the application rate of the fertilizer or soil amendment. Moss et al. noted this in their 2002 report: "When comparing metal contributions from land-applied materials, however, it is important to remember that application rates vary; mineral fertilizer application rates are generally much lower than biosolids or manure application rates, and the impacts from fertilizer contributions on a per-site basis should be considered accordingly. The higher metal concentrations in fertilizers are generally offset by the small amount of these concentrated materials that must be applied. Manure application rates are similar to application rates for biosolids, however, and, therefore, the applied metals can be similar for the two products on a per-site basis."

Kupper et al. (2014) also recognized this in their evaluation of heavy metal additions to soils from land application of source-separated organics (e.g. food scraps) digestate and compost in Switzerland. "For Co, Cu, Ni and Zn, manure was the main source [of metals additions to agricultural soils] (52%, 50%, 55% and 72% of the total for Co, Cu, Ni and Zn, respectively). Mineral fertilizer contributed the major

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part of the Cd and the Cr loads (33% and 42% of the total for Cd and Cr, respectively) and aerial deposition of the Pb load (53% of the total). The contribution to the total heavy metals input into agricultural soils of Switzerland associated to compost and digestates was between 2% (Cd) and 22% (Pb)." This research did not include evaluation of biosolids products.

Most biosolids are applied, by law, at the agronomic rate, the rate by which the crop being grown gets the amount of nitrogen (N) it needs and no more. This limits the total amount of trace contaminants, such as heavy metals, that are applied. Other soil amendments and fertilizers are not *required* to be applied at the agronomic rate, although it is becoming more of a standard practice for all farms to practice such nutrient management.

What should biosolids managers do with this information?

Producers and managers of biosolids products are advised to remain vigilant in helping monitor and reduce the inputs to wastewater systems of any contaminants of potential concern. By law, they must conduct routine tests for regulated elements and other contaminants at certified labs, submit results to regulatory agencies, and certify biosolids quality. When biosolids are land applied, they monitor soil quality and test for trace elements and other contaminants that may be locally of concern.

If biosolids and other soil amendments are properly tested and applied, it is possible to safely use them year after year indefinitely, providing critical organic matter and nutrients while recycling a local resource, stimulating carbon storage in soil, reducing demand for chemical fertilizers, and improving the economics of farm and land management.

Summary

The issue of heavy metals in biosolids has been thoroughly addressed:

- Research & risk assessment have determined safe levels for natural heavy metals and other contaminants in soils and biosolids.
- Regulations have incorporated these risk assessments and set limits where limits are needed.
- Operators certify, under penalty of law, that the biosolids they produce have been tested and meet regulatory standards.
- Pretreatment programs protect the quality of wastewater, the functioning of treatment plants, and the quality of biosolids by prohibiting, under penalty of law, the discharge of dangerous levels of contaminants to sewers.
- The concentrations of heavy metals in modern biosolids are low – well below regulatory, risk-based standards and do not pose a risk to public health and the environment when applied to soil in accordance with regulations.
- Even with the variability of heavy metals levels in biosolids, there is only a very low probability of any particular biosolids truckload exceeding regulatory standards, because modern biosolids have heavy metal concentrations well below the regulatory standards.

For more information, references, and data, contact the NEBRA office:
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***The North East Biosolids and Residuals Association (NEBRA)** is a 501(c)(3) non-profit professional association advancing the environmentally sound and publicly supported recycling of biosolids and other organic residuals in New England, New York, and eastern Canada. NEBRA membership includes the environmental professionals and organizations that produce, treat, test, consult on, and manage most of the region's biosolids and other large volume recyclable organic residuals. NEBRA is funded by membership fees, donations, and project grants. Its Board of Directors are from MA, ME, NH, NY, and Nova Scotia. NEBRA's financial statements and other information are open for public inspection during normal business hours. For more information: http://www.nebiosolids.org.*

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TABLE 1: Metals in Biosolids, Other Soil Amendments, & Fertilizers (NEBRA, 2015)

	BIOSOLIDS				SEPTAGE	SOILS		MANURES			WOOD ASH		COMPOSTS		FERTILIZERS - Traditional			FERTILIZERS - Natural & Organic			OTHER LAND APPLIED RESIDUALS	
	Regulatory Standard, U. S. EPA Part 503, Table 3	U. S. Sewage Sludge (not just biosolids) (EPA 2009, TNSSS)	New England Biosolids (NEBRA, 2001)	Reference Biosolids: New Hampshire (NH DES, 2012)	Average Septage (NH DES, 2001)	U. S. Planted/Cultivated Soils, All States (Smith et al., 2013)	Ontario Typical Range (ON Ministry of Env., 1993)	Manures (Alloway ed., 2013)	Liquid Pig Manure (Hölzel et. al. 2012)	Poultry Manure (Moss et. al., 2000)	Electrical Generator Wood Ash (NEBRA, 2001)	Home Wood Ash (Majeau et al., 2013)	U.K. Home Compost (Smith, 2009)	Greenwaste Compost, Germany (Amlinger 2004 in Smith, 2009)	Nitrogen Fertilizers (Alloway, ed. 2013)	Phosphatic Fertilizers (Alloway, ed. 2013)	Commercial Fertilizers (Washington Dept. of Ag., 2008 - 2014)	Natural Rock Phosphate (Washington Dept. of Ag)	Greensand (Washington Dept. of Ag)	Horn & Hooves (Möller & Schultheiss, 2014)	Paper Mill Residuals (M. Payne, 2001 -2003)	Ice Cream Plant Washwater (M. Payne, 2000-2001)
	low-metals standard	Mean	Range of means for MA, ME, NH, VT,	Mean of annual means (n = 81)	Mean (8 studies)	Mean (n= 1543)	Mean	World Range	Range (n = 305)	Mean	Mean	Mean (n = 25)	Mean (n = 64)	Mean (n = 490)	World Range	World Range	Mean (n=5)	1 sample	Mean (n=1)	Mean (N=13)	Mean (n=12 +)	Mean (n=4)
As	41	6.94	2 - 9	5.52	4.7	6.3	11	3 - 150		13	7	5			1 - 120	2 - 1200	15.7	110	16.2		0.8	1
Cd	39	2.64	2 - 3	4.08	7.6	0.3	0.71	0.3 - 0.8	0.08 - 5.3	2.4	6.3	3.2	1.77	0.70	0.05 - 8.5	0.1 - 170	34.5	2.9	0.609	< 0.2	3.67	1
Cr	no stnd	80.16	17 - 32	27.10	25.6	33.0	58	5.2 - 55	1.1 - 32.0		14	14	28	27	3 - 19	66 - 600				10.9	9	11.4
Cu	1500	553.13	310 - 490	385.76	1117	19.4	41	2 - 60	22.4 - 3387.6	465	45	214	52	33	1 - 15	1 - 300				34.7	20	23.8
Pb	300	76.19	49 - 91	32.71	102	20.1	45	6.6 - 350	2.0 - 26.7	46	39	39	124	61	2 - 1450	7 - 225	20.2	81	12	17.8	5	1.9
Hg	17	1.23	1 - 2	0.86	2.9	0.03	0.13	0.09 - 26	0.01 - 0.11		0.06	0.035		0.27	0.03 - 3	0.01 - 1.2	0.1	3.8	< 0.04	< 0.05	0.16	0.1
Mo	no stnd	15.30	7 - 13	10.39	-	0.9	1.0	0.05 - 3		19	4.7	3			1 - 7	0.1 - 60	41.7	< 3.8	4.39	< 5.4	3	2
Ni	420	48.32	18 - 26	20.87	20.1	15.5		7.8 - 30	3.1 - 97.3	16	19	17	18	18	7 - 38	7 - 38	84.0	66	45.4	6.03	13	7.6
Se	36	7.00	2 - 6	5.29	2.1	0.4	0.93	2.4			0.63	0.35				0.5 - 25	0.2	9.3	1.61	< 2.2	0.35	1
Zn	2800	970.01	419 - 663	730.36	727	58.9	120	15 - 250	93 - 8239	602	537	1319	240	168	1 - 42	50 - 1450	3818	120	127	179	173	29.40

All data in mg/kg (parts per million). Orange indicates a contaminant value greater than (>) the reference biosolids contaminant value (NH biosolids means, 2012.
More notes & details: See NEBRA spreadsheet "Metals & Other Contaminants in Biosolids, Other Soil Amendments, & Fertilizers," available at http://www.nebiosolids.org/resources/#/heavy-metals-trace-elements/)

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The Characterization of Feces and Urine: A Review of the Literature to Inform Advanced Treatment Technology

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The safe disposal of human excreta is of paramount importance for the health and welfare of populations living in low income countries as well as the prevention of pollution to the surrounding environment. On-site sanitation (OSS) systems are the most numerous means of treating excreta in low income countries, these facilities aim at treating human waste at source and can provide a hygienic and affordable method of waste disposal. However, current OSS systems need improvement and require further research and development. Development of OSS facilities that treat excreta at, or close to, its source require knowledge of the waste stream entering the system. Data regarding the generation rate and the chemical and physical composition of fresh feces and urine was collected from the medical literature as well as the treatability sector. The data were summarized and statistical analysis was used to quantify the major factors that were a significant cause of variability. The impact of this data on biological processes, thermal processes, physical separators, and chemical processes was then assessed. Results showed that the median fecal wet mass production was 128 g/cap/day, with a median dry mass of 29 g/cap/day. Fecal output in healthy individuals was 1.20 defecations per 24 hr period and the main factor affecting fecal mass was the fiber intake of the population.

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Fecal wet mass values were increased by a factor of 2 in low income countries (high fiber intakes) in comparison to values found in high income countries (low fiber intakes). Feces had a median pH of 6.64 and were composed of 74.6% water. Bacterial biomass is the major component (25–54% of dry solids) of the organic fraction of the feces. Undigested carbohydrate, fiber, protein, and fat comprise the remainder and the amounts depend on diet and diarrhea prevalence in the population. The inorganic component of the feces is primarily undigested dietary elements that also depend on dietary supply. Median urine generation rates were 1.42 L/cap/day with a dry solids content of 59 g/cap/day. Variation in the volume and composition of urine is caused by differences in physical exertion, environmental conditions, as well as water, salt, and high protein intakes. Urine has a pH 6.2 and contains the largest fractions of nitrogen, phosphorus, and potassium released from the body. The urinary excretion of nitrogen was significant (10.98 g/cap/day) with urea the most predominant constituent making up over 50% of total organic solids. The dietary intake of food and fluid is the major cause of variation in both the fecal and urine composition and these variables should always be considered if the generation rate, physical, and chemical composition of feces and urine is to be accurately predicted.

KEY WORDS: fecal characteristics, feces, feces treatment, human excreta, urine, urine characteristics

1. INTRODUCTION

An estimated 2.6 billion people in the world lack access to improved sanitation, defined as the hygienic separation of human excreta from human contact (WHO/UNICEF, 2012). Diseases that are associated with inadequate sanitation are particularly associated with poverty and account for 10% of the total disease burden worldwide (Prüss-Üstün et al., 2008). Poor sanitation and fecal sludge management not only have negative impacts on human health but also affect the environment through the contamination of water bodies, soils, and food sources (Peletz et al., 2011; Ziegelbauer et al., 2012). In 2010, 72% of sanitation facilities in Sub-Saharan Africa and 59% in Southern Asia were classified as "unimproved" (WHO/UNICEF, 2012). On-site sanitation (OSS) facilities are the predominant form of excreta disposal in urban populations of low income areas; for example, in urban areas of Ghana and Tanzania 85% of inhabitants are served by OSS facilities and in urban areas of the Philippines 98% rely on OSS facilities (Montangero and Strauss, 2004). However, when these facilities need emptying, there are often inadequate facilities or financial disincentives for the proper disposal of fecal sludge meaning that pits remain full and unusable or if emptied, sludge

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is disposed of directly into the environment contaminating water resources (Ingallinella et al., 2002). This problem has inspired the development of OSS technologies that treat excreta directly at or close to its source, producing safe and beneficial products with no need for further transport. This factor is illustrated by a rapid rise in research and development in OSS technology, with the Bill and Melinda Gates Foundation (BMGF) funding 16 "Reinvent the Toilet Challenge" (RTTC) research projects worldwide since 2011, with the second round of grants totaling nearly US$3.4 million in 2012 (Global Development Program, 2014). This trend is continuing with the BMGF investing in regional programs, for example, US$5 million has been awarded to Chinese research institutes to drive research and development into new OSS systems (Global Development Program, 2014).

Knowledge of the waste that enters treatment systems is a basic prerequisite for the design and development of future technology. There is information on conventional sanitary sewage (Henze et al., 2001; Tchobanoglous et al., 2003) but this material has a different composition to fresh feces and urine which has not undergone any degradation processes and will have substantially less water or gray water addition. Instead generation rates and the chemical composition of feces and urine in the human population are key factors to be understood by OSS technology developers. A number of medical studies have determined the fecal and urine output of human populations, however the data are specific to distinct populations defined by geography, age, ethnicity, disease, and diet. There have so far been no attempts to summarize these data and understand the major causes of variation. The aim of this study is to review the variation, generation rate, and chemical and physical composition of the solid and liquid fractions of human excreta that would supply OSS technologies in developing countries. An assessment will then be made on how the results and any variation found will impact on potential treatment technology.

2. METHODS

Generation rate, composition, and physical and chemical nature of both feces and urine were recorded as of Table 1. Each recorded datum was the mean of the data from the reported study. Some published papers reported two or more independent studies so these papers contributed more than one value to the data set. The mean and median of each variable were both calculated as measures of central tendency and data were checked for normality by calculating a coefficient of skewness (Young, 1962):

$$Skewness = n * M_3 / \left[(n-1) * (n-2) * \sigma^3\right] \tag{1}$$

$$M_3 = \sum (x_i - Mean_x)^3 \tag{2}$$

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TABLE 1. Measured variables for feces and urine

Variable	Feces unit of measure	Urine unit of measure
Generation	g/cap/day	L/cap/day
Frequency of defecation	motions/24 hr	urinations/24 hr
Water content	% total mass	% total mass
Organic composition	% total mass	% dry mass
Components of solids	% total mass	% total mass
Inorganic composition	% dry mass	% dry mass
Daily excretion of elements	g/cap/day	g/cap/day, mg/L
Chemical nature		
pH	pH	pH
COD and BOD	mg/g wet mass	mg/L
Physical form		
Bristol stool form	Linear scale (1–7)	
Diarrhea prevalence	% of population	

σ = *Standard deviation*
n = *Valid number of cases*

Box and whisker plots were created using Statistica 11 software (Statsoft Inc., Tulsa, OK, USA, 2011). Outliers of each data set were defined using a standard default outlier coefficient value (Burns et al., 2005).

$$\begin{aligned}&Outliers = Upper\ value\ of\ the\ 75th\ percentile * outlier\ coefficient\ of\ 1.5\\&Extreme\ values = Upper\ value\ of\ 75th\ percentile * 2\ outlier\ coefficient\end{aligned} \tag{3}$$

No outliers were removed from the data set but were identified in the graphical output. Full statistical calculations were only conducted on variables that had at least seven values but a median value is given for data when there were less than seven values.

A summary of studies used in the statistical analysis are outlined in Table 2, including the location and number of studies. A large proportion (80%) of the data set was from studies conducted in Europe and North America. A distinction was therefore made between low and high income countries by the measure of development; using the Human Development Index (HDI), a composite index measuring average achievement in three basic dimensions of human development; life expectancy, education, and income (UNDP, 2011).

Preliminary data analysis indicated that fiber intake was a major cause of variation in fecal generation and composition. There were a sufficient number of studies that had examined the effects of fiber intake on fecal output to enable further analysis to be undertaken on these data. The total dietary fiber intake was related to the generation of feces in linear and nonlinear regression analyses.

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TABLE 2. The geographical location and human development index ranking of studies used in statistical analysis

Country	n	HDI*	References
Africa	2	3/4[a]	Cranston and Burkitt (1975), Burkitt et al. (1980)
Australia	2	1	Birkett et al. (1996), Hovey et al. (2003)
Burma	1	4	Myo-Kin et al. (1994)
Canada	3	1	Burkitt et al. (1980), Vuksan et al. (1999)
China	3	2	Jie et al. (2000), Chen et al. (2008), Bai and Wang (2010)
Denmark	2	1	Maclennan and Jensen (1977), Jensen et al. (1982)
Developing countries	2	3/4[a]	Feachem et al. (1978)
Europe and North America	1	1/2[b]	Feachem et al. (1978)
European	1	1[b]	Mykkänen et al. (1998)
Finland	4	1	Reddy et al. (1975), Reddy et al. (1978), Jensen et al. (1982), Mykkänen et al. (1998)
Germany	1	1	Erhardt et al. (1997)
Guatemala	1	3	Calloway and Kretsch (1978)
Holland	4	1	Stasse-Wolthuis et al. (1980), Van Faassen et al. (1993), Gaillard (2002), Wierdsma et al. (2011)
India	1	3	Shetty and Kurpad (1986)
Iran	1	2	Adibi et al. (2007)
Japan	7	1	Glober et al. (1977), Polprasert and Valencia (1981), Tarida et al. (1984), Saitoh et al. (1999), Danjo et al. (2008), Shinohara et al. (2010), Hotta and Funamizu (2009)
Kenya	1	4	Cranston and Burkitt (1975)
New Zealand	1	1	Pomare et al. (1981)
North America	1	1[b]	Vuksan et al. (2008)
Peru	1	2	Crofts (1975)
Singapore	1	1	Chen et al. (2000)
South Africa	2	3	Burkitt et al. (1972), Walker (1975)
Spain	1	1	Roig et al. (1993)
Sweden	4	1	Reddy et al. (1978), Vinneras (2002), Vinnerås et al. (2006)
Thailand	2	2	Danivat et al. (1988), Schouw et al. (2002)
Tonga	1	2	Pomare et al. (1981)
UK	26	1	Olmsted et al. (1934), Connell et al. (1965), Southgate and Durnin (1970), Burkitt et al. (1972), Goy et al. (1976), Wyman et al. (1978), Prynne and Southgate (1979), Stephen and Cummings (1980), Eastwood et al. (1984), Eastwood et al. (1986), Davies et al. (1986), Cummings et al. (1987), Sandler and Drossman (1987), Cummings et al. (1992), Murphy et al. (1993), Cummings et al. (1996), Lewis and Heaton (1997), Chen et al. (1998), Reddy et al. (1998), Rivero-Marcotegui et al. (1998), Aichbichler et al. (1998), Almeida et al. (1999), Magee et al. (2000), Chaplin et al. (2000), Woodmansey et al. (2004), Silvester et al. (2011)

(Continued on next page)

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TABLE 2. The geographical location and human development index ranking of studies used in statistical analysis *(Continued)*

Country	n	HDI*	References
USA	18	1	Canfield et al. (1963), Watts et al. (1963), Diem and Lentner (1970), Goldsmith and Burkitt (1975), Cummings et al. (1978), Glober et al. (1977), Goldberg et al. (1977), Beyer and Flynn (1978), Reddy et al. (1978), Calloway and Kretsch (1978), Kien et al. (1981), Polprasert and Valencia (1981), Tucker et al. (1981), Schubert et al. (1984), Parker and Gallagher (1988), Zuckerman, et al. (1995), Aichbichler et al. (1998), McRorie et al. (2000)

*Human Development Index Classifications (UNDP, 2011): 1. Very high, 2. High, 3. Medium, 4. Low.
[a]Classification not available, presumed to be ranking 3 or 4.
[b]Classification not available, presumed to be ranking 1 or 2.

3. RESULTS

3.1 Feces Generation

Fecal wet mass values have a median figure of 128 g/cap/day. This is from a distribution of 116 mean values from studies reporting healthy individuals, with a large minimum and maximum range of 51–796 g/cap/day (Figure 1). However, as mean values for each study were recorded, individual variation

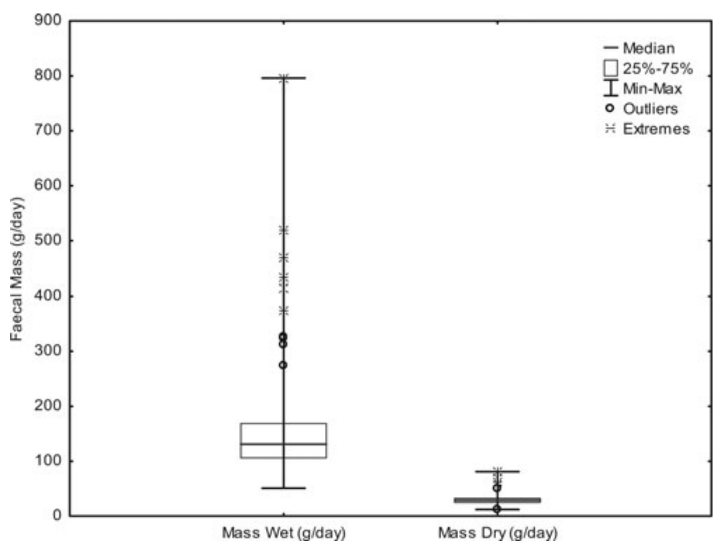

FIGURE 1. Daily wet and dry mass of feces produced by human populations (g/cap/day). Outliers represent the upper value of the 75th percentile multiplied by the outlier coefficient (1.5), (extreme values = upper value of 75th percentile *2 outlier coefficient). Fecal wet mass generation (n = 112) has a large range and was an abnormal data set. Fecal dry mass (n = 61) showed a smaller range with fewer outliers and extreme values.

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TABLE 3. Daily wet and dry mass produced by humans from low and high income populations

	Wet weight (g/cap/day) High income*	Wet weight (g/cap/day) Low income*	Dry weight (g/cap/day) High income*	Dry weight (g/cap/day) Low income*
Median	126	250	28	38
n	95	17	57	8
Minimum	51	75	12	18
Maximum	796	520	81	62
Skewness	4.178	0.598	2.378	0.098
Std. error of skewness	0.248	0.550	0.327	0.752
Mean	149	243	30	39
St dev	95.0	130.2	11.7	14.1
Variance	9024	16,960	136	201

*Classifications acquired from the 2011 HDI report (UNDP, 2011) where the four tiers were split into two sections with "very high" and "high" comprising the high income classification and "medium" and "low" comprising the low income classification.

within these studies is not accounted for; if all values are recorded the range extends to 15–1505 g/cap/day. The data set for mean wet fecal generation had a positive skew, hence the mean was greater than the median. The low income countries data set was not as skewed as the high income countries (Table 3). This is likely a result of the wider range of diets that can be consumed by populations in richer countries. A statistically significant difference ($t = 2.87$, $p < .05$) between mean values of high income countries and low income countries was found in regards to wet fecal weight. As a collective group high income countries had relatively small per capita wet fecal weights in comparison to low income countries. However, between individual studies there was a large variation of 51–796 g/cap/day, despite all studies reporting healthy individuals. For low income countries the median value of 250 g/cap/day was larger in comparison to the median value of 126 g/cap/day in high income countries.

The mean weight of children's feces (3–18 years) has been recorded between 75 and 374 g/cap/day (Burkitt et al., 1972; Tandon and Tandon, 1975; Burkitt et al., 1980; Almeida et al., 1999; Schouw et al., 2002). Infants (1–4 years) were shown to have a mean stool weight of 85 g/cap/day with no significant difference found between the age of children in years, however, a weak correlation was found between the infants age in months and total stool weight ($r = 0.125$, $p < .029$) (Myo-Khin et al., 1994). Mean values for elderly subjects (aged 65 years or more) were reported at 158 g/cap/day by Mykkänen et al. (1998) and 70 g/cap/day by Woodmansey et al. (2004).

Median dry stool weight was 29 g/cap/day which were recorded from the mean values of 60 studies, with a range of means of 12–81 g/cap/day (Figure 1). Again, individual variation within these studies was not accounted for as mean values of these populations were taken; ranges of minimum and

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TABLE 4. The effect of diet type on fecal characteristics

Diet type*	Fiber intake (g/day)	Number of subjects in study	Fecal mass wet (g/day)	Fecal mass dry (g/day)	Stool frequency (motions per 24 hr)	Moisture (%)	Fecal pH	References
Omnivore	23	17	153		1			Davies et al. (1986)
Vegetarian	37	17	168		1.2			Davies et al. (1986)
Vegan	47	17	225		1.7			Davies et al. (1986)
Omnivore		14			1.4	73.5		Goldberg et al. (1977)
Vegetarian		14			1.8	73.3		Goldberg et al. (1977)
Omnivore		66	131.9					Lewis and Heaton (1997)
Omnivore	16.6	22	117	30.8		72.6	6.65	Reddy et al. (1998)
Vegetarian	16.2	22	186	36		78.9	6.18	Reddy et al. (1998)
Vegetarian	29.3	18	160	38.4		74.6	6.55	Reddy et al. (1998)
Omnivore[a]	12	8	129	32.8		74	7	Silvester et al. (1997)
Omnivore[b]	11	8	118	32		70.7	7.2	Silvester et al. (1997)
Omnivore	27.3	149	119	27.1	0.9		6.8	Van Faassen et al. (1993)
Vegetarian	40.8	11	189	27.9	1.5		6.8	Van Faassen et al. (1993)

*O: Omnivore, V: Vegetarian, VN: Vegan.
[a]Low meat diet (68 g/day protein).
[b]High meat diet (192 g/day protein).

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TABLE 5. Daily loadings and concentrations of elements in feces (wet weight)

	Value (g/cap/day)	Value (g/kg)	References
Total P	0.35	3.40	Vinnerås et al. (2006)
	0.5	1.83	Czemiel (2000)
	0.5	3.59	Vinneras (2002)
	0.51	1.77	Goldblith and Wick (1961)
	0.65–0.87	7.76–8.92	Calloway and Margen (1971)
	0.5	3.8	Meinzinger and Oldenburg (2009)
	0.69–2.5	4.80–9.86	Chaggu (2004)
	0.9–2.7		Wignarajah et al. (2003)
Total K	0.20–0.24	1.78–2.14	Calloway and Margen (1971)
	0.47	3.10	Goldblith and Wick (1961)
	0.75–0.88		Wignarajah et al. (2003)
	0.8	4.936	Eastwood et al. (1984)
	0.8–1.0		Kujawa-Roeleveld and Zeeman (2006)
	0.7	3.3	Meinzinger and Oldenburg (2009)
	0.8–2.1	2.712	Chaggu (2004)
	1.48–2.52	7.16	Vinnerås et al. (2006)
Na	0.12	0.80	Goldblith and Wick (1961)
	0.8 (0.3–4.1)	4.94	Eastwood et al. (1984)
Ca	0.1–1		Wignarajah et al. (2003)
	2.9–3.6		Chaggu (2004)
	0.53		Kujawa-Roeleveld and Zeeman (2006)
	0.61	3.77	Eastwood et al. (1984)
	0.64	4.27	Goldblith and Wick (1961)
	0.96–1.12	2.68	Calloway and Margen (1971)
Mg	0.15	0.93	Eastwood et al. (1984)
	0.18		Kujawa-Roeleveld and Zeeman (2006)
	0.20	1.33	Goldblith and Wick (1961)
	0.30–0.34	2.86	Calloway and Margen (1971)
Cl	0.09	0.6	Goldblith and Wick (1961)
S	0.13	0.87	Goldblith and Wick (1961)
	0.2		Meinzinger and Oldenburg (2009)
	(mg/cap/day)	(mg/kg)	
Cu	1.02	6.8	Goldblith and Wick (1961)
	1.10		Kujawa-Roeleveld and Zeeman (2006)
	1.5–2.1		Wignarajah et al. (2003)
Fe	30	200	Goldblith and Wick (1961)
	700–1000		Wignarajah et al. (2003)
Pb	0.03–0.07	0.12–0.27	Schouw et al. (2002)
	0.02–0.03		Hansen and Tjell (1979)
	1.26	6.38	Vinnerås et al. (2006)
Mn	24–90		Wignarajah et al. (2003)
Mo	2–4		Wignarajah et al. (2003)
Zn	7.85	48.46	Eastwood et al. (1984)
	5–10		Wignarajah et al. (2003)
	10.68		Kujawa-Roeleveld and Zeeman (2006)
	13.31	67.49	Vinnerås et al. (2006)
Ni	0.08–0.09		Hansen and Tjell (1979)
	0.3	1.52	Vinnerås et al. (2006)
	0.3	1.15	Schouw et al. (2002)
Cr	0.02–0.03		Hansen and Tjell (1979)
	0.08	0.31	Schouw et al. (2002)
	0.18	0.91	Vinnerås et al. (2006)
Cd	0.07	0.27	Schouw et al. (2002)
	1.26	6.39	Vinnerås et al. (2006)
Hg	0.007	0.04	Vinnerås et al. (2006)

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maximum values taking into account individual variation within these studies was subsequently larger at 4–102 g/cap/day dry solids. The data set was not of a normal distribution with a positive skew of 1.8. This was also due to the skewed distribution of values from high income countries (Table 3). The median dry weight of feces is 25% of the wet weight of feces (n = 45) with values in the range of 11–34% reported (Figure 1).

3.1.1 Factors Affecting Fecal Mass

The major factors leading to variation in fecal generation rate are total food intake, body weight, and diet. Parker and Gallagher (1992) found that mean daily stool weight was correlated ($p < .001$) with calorie intake (energy intake can act as a measure of food intake); however, they found that this only accounted for 28% of the variation seen in individual stool output. Body weight also represents differing energy intake requirements; for example, as a guideline a healthy adult requires 20–25 kcal/per kilogram of body weight (Moyes and McKee, 2008). The increasing body weight therefore reflects increasing energy intake which in turn can act as a measure of total food intake. Food intake and body weight therefore have an influence over fecal weight and this accounts for variables such as gender (Stephen et al., 1986; Lampe et al., 1993; Poullis et al., 2004) and race (Burkitt et al., 1972; Goldsmith and Burkitt, 1975) that have been observed as being significant within the literature.

Human diet is also a factor that can impact the generation rate and composition of feces (Table 4). Fiber intake is often cited for causing variation in feces production, for example, by Vuksan et al. (2008). Regression analysis of secondary data presented in 25 studies where fiber intake was recorded was conducted and results show that fecal wet mass was positively correlated with fiber intake ($r = 2.96 \pm 1.13$, $p = .017$) (Figure 2).

The effect of dietary fiber on fecal weight is highly dependent upon the type of fiber consumed (non-degradable or degradable). Non-degradable fiber undergoes minimal changes in the digestive tract as it is relatively un-fermentable and shortens colonic transit time (Bijkerk et al., 2004); wet fecal mass has been negatively correlated with transit time, $r = -0.22$, $p < .05$ (Eastwood et al., 1984). Non-degradable fiber has a high water holding capacity which promotes bulk and increased defecation frequency; extensive studies with non-degradable cereal fibers have shown this (Cummings et al., 1992; Hughes et al., 2002; Vuksan et al., 2008). In a study on wheat bran by Vuksan et al. (2008) a ratio of 2.8 g stool/per g additional fiber on top of a control diet was observed. Degradable fibers can also cause an increase in fecal mass. Highly degradable types of fiber (such as cabbage fiber or oat bran) are fermented in the colon by bacteria much more than non-degradable fibers (Bijkerk et al., 2004). However, degradable fibers still increase fecal weights due to the proliferation of the bacterial component that is stimulated by the presence of a fermentable substrate (Garrow et al., 1993); the resultant

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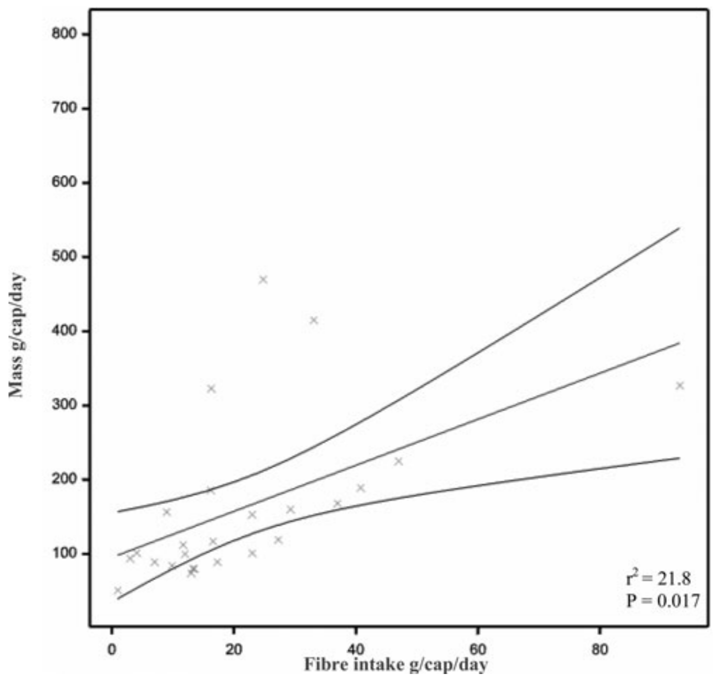

FIGURE 2. Fitted and observed relationship with 95% confidence limits. Values from 22 studies where fiber intake was recorded. Three large outliers were recorded, however, no reason could be found to exclude these results from the study. There was a significant correlation between dietary fiber intake and fecal output (r^2 = 21.8, p = .017) with an intercept 101.3 ± 34.3 and a regression coefficient of 2.96 ± 1.13.

increase in bacterial mass is soft, bulky, and water retaining (FAO/WHO, 1997). Any alteration in the bacterial biomass component is significant as it can make up to 55% of total fecal solids (Stephen and Cummings, 1980). Therefore, the impact of dietary fiber on increasing fecal mass is dependent on the type of fiber consumed.

Polysacharides such as resistant starches (RS) have similar properties to fiber and have also been shown to increase fecal wet weight in many studies (Shetty and Kurpad, 1986; Cummings et al., 1996; Silvester et al., 1997). Diets high in RS have shown a significant increase in fecal wet and dry weight; (Phillips et al., 1995) concluded that for every 1 g RS consumed (mean 34 g/day) there was an increase in the fecal wet weight of 1.8 g. Undigested starch, as measured by dietary intake, reaching the colon was found to increase fecal output (g wet weight/day) by 42% (Phillips et al., 1995). This correlation can be largely attributed to increases in bacterial biomass with fermentation (Cummings et al., 1996).

3.1.2 Stool Frequency

Defecation frequency provides an indication for design parameters relating to treatability as it provides an indication of how often a facility may be used.

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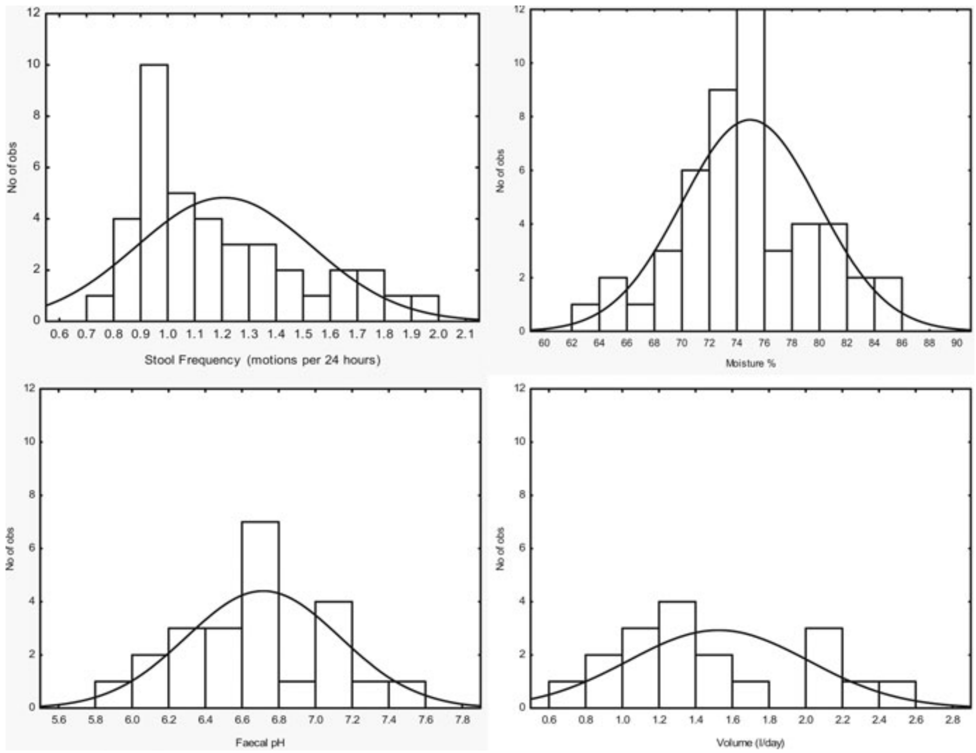

FIGURE 3. *Top left:* Mean stool frequency in healthy subjects from a wide range of studies (n = 39). Ranges of individuals within these studies varied from 0.21 to 2.54 motions per 24 hr. *Top right:* Mean moisture composition of feces (n = 47). *Bottom left:* Mean fecal pH values from a range of studies (n = 28) consuming a variety of different diets. *Bottom right:* Mean volume of total urine excreted (n = 14).

Stool frequency also provides an indication of the resultant texture and form of the fecal matter (see physical form section). Mean stool frequency across studies (n = 39) ranged from 0.74 to 1.97 motions per 24 hr with a median value of 1.10 motions per 24 hr period (Figure 3). This represents a guideline figure for a population majority, however, within this variability exists. In a study by Parker and Gallagher (1988) of over 25,000 days worth of data, individuals had a range of means between 0.21 and 2.54 movements per 24 hr illustrating the variability that can occur for individuals in the same population. In a study of a UK population defecations were recorded per hour of the day; the majority of defecations, 61% and 59% in men and women respectively occurred in the morning (06:00–10:00) with peak times in men (20%) occurring between 07:00 and 08:00 and an hour later in women (21%) (Heaton et al., 1992). Another small peak in defecation timing was recorded at 17:00 and 18:00 which is a common time for the evening meal and few defecations were recorded during the night (01:00 to 05:00) (Heaton et al., 1992). The increase in defecation after meal times is primarily due to the resultant increased motor activity of the colon (Christensen, 1985).

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Stool frequency is impacted by an individual's health (see physical form section) as well as their fiber intake which is associated with more rapid transit times (Gear et al., 1981). Fiber intake has been positively correlated with stool frequency (r = 0.8, $p < .001$ wet weight; r = 0.5, $p = .008$ dry weight) (Southgate et al., 1976). The inclusion of fiber from fruit and vegetables in the diet has been proven to decrease transit time ($p < .05$) and increase the number of defecations ($p < .001$) (Kelsay et al., 1978). For instance, in a study by Vuksan et al. (2008) high fiber breakfast cereals induced a shorter intestinal transit time and an increased stool frequency. In a meta-analysis of five relevant randomized controlled trials by Yang et al. (2012) dietary fiber was proven to increase stool frequency (odds ratio = 1.19; 95% CI: 0.58–1.80, $p < .05$).

Amongst adults no consistent relationship between frequency of defecation and age was observed (Heaton et al., 1992). Similarly amongst infants there was no significant difference in frequency of defecation between different age categories (Myo-Khin et al., 1994). A lower defecation frequency has been observed in females than in males (Van Faassen et al., 1993; Zuckerman et al., 1995; Chen et al., 2000) and this was accounted for by the longer intestinal transit time of females ($p < .02$) (Gear et al., 1981). However, in children no significant difference was observed between the defecation frequency of boys (0.99/24 hr) and girls (0.96/24 hr) (Myo-Khin et al., 1994). A study by Sandler and Drossman (1987) undertaken in the USA, indicated that the daily mean number of stools varied by race and by sex; whites had more frequent stools than non-whites at 1.3 versus 0.86 defecations/24 hr respectively and men had more frequent stools than women at 1.31 versus 0.96 defecations/24 hr respectively. Conversely, in a study of an Iranian population by Adibi et al. (2007) men were reported to have fewer bowel frequencies per day (1.78 versus 1.97).

3.2 Composition

Feces are composed of water, protein, undigested fats, polysaccharides, bacterial biomass, ash, and undigested food residues. The major elements in feces as a percentage of wet weight are oxygen 74%, hydrogen 10%, carbon 5%, and nitrogen 0.7%, including the hydrogen and oxygen present in the water fraction of the feces (Snyder et al., 1975).

Feces compose a median value of 75% H_2O (n = 47) with a range of 63–86% across mean values of studies (Figure 3), variation can be attributed to differences in fiber intake as non-degradable fiber absorbs more water in the colon (Eastwood, 1973); therefore, as shown in a study by Reddy et al. (1998) those with vegetarian diets will have a higher moisture content of 78.9% whereas those who consume less fiber and more protein will have a lower moisture content of 72.6% ($p = .001$). Fiber intake also affects transit time, which has been positively correlated (r = 0.4, $p = .03$) with% dry

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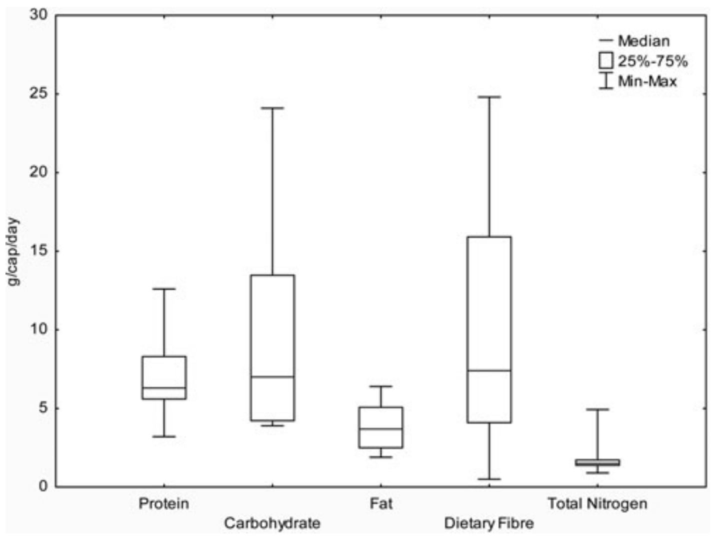

FIGURE 4. Daily per capita weights of organic fractions excreted in feces.

matter (Silvester et al., 1997), showing the shorter the intestinal transit time the higher the water content. Variation in moisture content has been shown to vary with age; elderly people were found to excrete the highest amount of water in excreta of all age groups by Schouw et al. (2002). Further deviations from the median value can be caused by illness (see physical composition section). The mean generation rate of fecal water (n = 47) is 0.1 L/cap/day. Average pH values for fecal water have been recorded at pH 6.9 with a range of pH 5.0–8.0 (Mai et al., 2009).

3.2.1 Organic Fraction

The remaining 25% of feces is therefore composed of solid material. Of the solid fraction organic material makes up between 84% and 93% (Feachem et al., 1978; Nwaneri et al., 2008; Bai and Wang, 2011). The organic solids fraction can be further broken down to the fractions of 25–54% bacterial biomass (Stephen and Cummings, 1980; Guyton and Hall, 2000), 2–25% protein or nitrogenous matter (in addition 50% of bacterial biomass is protein) (Canfield et al., 1963; Volk and Rummel, 1987), 25% carbohydrate or any other nonnitrogenous undigested plant matter (Volk and Rummel, 1987), and 2–15% undigested lipids (Kien et al., 1981; Chen et al., 1998; Wierdsma et al., 2011). These fractions are highly dependent on dietary intake and its biological availability.

The organic fraction therefore makes up the majority of dried solids. Carbon content of feces is between 44% and 55% of dried solids (Feachem et al., 1978; Strauss, 1985) or 7 g/cap/day (Snyder et al., 1975). Volatile solids were shown to comprise 92% of the total solids (TS) fraction of feces (Fry and Merrill, 1973). The bulk organic content of feces can also be measured by chemical oxygen demand (COD) and biological oxygen demand (BOD)

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TABLE 6. Loading rates and concentration of BOD and COD in feces

BOD (g/cap/day)	COD (g/cap/_day)	COD (mg/L)	COD (mg/g dry)	COD (mg/g wet)	References
1223*	1668*				Vinnerås et al. (2006)
		48,900			Takahashi et al. (1989)
			1450		Lopez Zavala et al. (2002)
			1380		Almeida et al. (1999)
			1130		Nwaneri et al. (2008)
45					Heinss et al. (1998)
14–34	46–55				Kujawa-Roeleveld and Zeeman (2006)
			567		Chaggu et al. (2007)
			1671		Bai and Wang (2010)
38	96				Choi et al. (2004)
19.3					Fourie and Van Ryneveld (1995)
			1448	354	Buckley et al. (2008)
32	50				Meinzinger and Oldenburg (2009)
		46,230–78,310			Chaggu (2004)

*Includes toilet paper.

values (Table 6). Per capita daily values for BOD were between 14 and 33.5 g/cap/day. Values of COD were measured between 46 and 96 g/cap/day or 567 and 1671 mg/g dry fecal sample. Gas production of human feces was placed at 0.02–0.28 per kg wet feces (United Nations, 1984).

3.2.2 Bacterial Composition

A significant proportion of fecal mass consists of bacteria with estimates of combined dead and living bacteria of approximately 25–54% of dry solids (Stephen and Cummings, 1980; Guyton and Hall, 2000; Achour et al., 2006). The wide variation observed is due to differing methodology used between microscopic counting techniques and the separating of bacterial biomass. The high nitrogen content of feces is partly due to undigested protein voided in the feces but is also due to the significant protein content of bacterial biomass in the feces, a figure of 50% protein was proposed by Volk and Rummel (1987); however, a more precise figure is not possible to determine due to uncertainties in the total bacterial composition of feces. A detailed break down of the microbial composition of feces has been compiled by Stephen and Cummings (1980).

3.2.3 Nitrogen/Protein

Nitrogen voided in feces is also recorded as protein. The protein content of feces can be estimated by multiplying the determined nitrogen content by a nitrogen-to-protein conversion factor. The Jones' (1931) factor has been used

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extensively, with a standard default conversion factor of 6.25 (Mariotti et al., 2008), which is based on the average nitrogen content and composition of proteins. Data from measured mean values in feces provides a median figure for protein daily loadings of 6.3 g/cap/day with a range of 3.2–16.2 (n = 7) and for nitrogen 1.8 g/cap/day with a range of 0.9–4.9 (n = 18) (Figure 4). Fecal nitrogen is present in the form of undigested dietary protein, nucleic acids, protein from bacteria and shed intestinal mucosal cells as well as being present in secreted mucus (Canfield et al., 1963; Bender and Bender, 1997). Nitrogen can make up 5–7% of the dried solids (Feachem et al., 1978) and of the nitrogen voided in the feces fraction 50% is thought to be water-soluble (Montangero and Belevi, 2007).

Mean endogenous nitrogen excretion in 14 males has been measured at 0.96 g/cap/day in feces, or 38 mg/kg body weight by Calloway and Margen (1971); this is the minimum nitrogen loading that can be expected. The safe rate of nitrogen intake to maintain nitrogen balance is 0.75 g protein/kg body weight/day (FAO/WHO/UNU, 1985) and as a guideline figure of nitrogen voided in feces Bender and Bender (1997) concluded that when a healthy human is in nitrogen equilibrium, nitrogen excretion will equal ±5% of intake. Variation in the protein content of feces is largely dependent on protein intake in the diet; however, the digestion rate of protein has been shown to vary from 69% to 93% as a result of differing types of protein in the diet (Southgate and Durnin, 1970; Calloway and Kretsch, 1978). It should be noted that the majority of nitrogen output is in the urine fraction with this study showing that only 14% is voided through the feces (1.8 g/cap/day) and the majority is excreted in urine (10.7 g/cap/day).

Concentrations of the differing nitrogenous fractions have also been recorded; Silvester et al. (1997) recorded fecal ammonia concentrations on low (68 g/day) and high (192 g/day) protein diets with values of 12 mmol/kg (1.4 mmol/day) and 24 mmol/kg (2.9 mmol/day) respectively. Fecal nitrite levels were also found to be increased twofold on high protein diets, with values of 1678 μg/kg, in comparison to the lower protein diet with 829 μg/kg (Silvester et al., 1997).

3.2.4 Lipids

Fats contribute between 2.4% and 8% of the wet weight of feces (Canfield et al., 1963; Kien et al., 1981; Rivero-Marcotegui et al., 1998; Guyton and Hall, 2000; Wierdsma et al., 2011) or 8.7–16.0% of the dry weight of feces (Calloway and Kretsch, 1978; Tarpila et al., 1978; Stephen et al., 1986). Daily loadings of fat in the fecal fraction from the mean values of 8 studies gave a median value of 4.1 g/cap/day and a range of 1.9–6.4 g/cap/day (Figure 4). However, it should be noted that only one out of the eight studies was from outside Europe and North America (Guatemala): with this individual study presenting the lowest figure in the range of values (1.9 g/cap/day). Age differences have been observed, with infants voiding lower amounts of fecal

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fat 0.8–3.2 (Shmerling et al., 1970) and children aged 1–11 years voiding 0.9–5.9 (mean 3.0) g/cap/day of fat (Kuo and Huang, 1965). As would be expected fecal fat is positively correlated ($p < .001$) with fecal wet mass and has also been positively correlated with fiber intake (Eastwood et al., 1984). Fecal fat excretion is dependent on dietary intake; however, even with no fat intake excretion of fat occurs. At high levels of fat intake there is no correlation between fat intake and fecal fat excretion (Gades and Stern, 2012). A significant positive correlation ($r = 0.56$, $p = .007$) between calcium intake and fecal fat excretion was found by Jacobsen et al. (2005) with fecal fat excretion on a high calcium diet increasing from 7% to 18% of dietary fat intake and an increase of 100 mg calcium resulting in an increase of 5.4 g in fat excretion. This increase is thought to be due to an interaction between calcium and fatty acids, which causes insoluble calcium fatty acids to form and resultantly reduces fat absorption and increases fat excretion (Jacobsen et al., 2005). Fat found within feces comes from bacteria and fat in the shredded epithelial cells as well as from the undigested dietary intake of fat (Guyton and Hall, 2000). Broadly the fat content includes substances such as fatty acids, waxes, and phosphoglycerides.

3.2.5 Carbohydrate and Energy Value

The carbohydrate fraction is largely made up of undigested cellulose, vegetable fibers, and pentosan (Canfield et al., 1963). Feces do not contain large quantities of carbohydrates as the majority of what is consumed is absorbed; however, undigested and unabsorbed fractions (RS) remain. A median value ($n = 10$) of 9 g/cap/day carbohydrate in feces was recorded with a range of 4–24 g/cap/day. The vast majority of studies were again conducted in North America and Europe with only one study in Peru presenting values in the center of this range. The calorific content of feces had a median value ($n = 14$) of 132 kcal/cap/day (range: 49–347 kcal/cap/day). By using the median value of production (32 g/cap/day) a calorific value of 4115 kcal/kg dry solids can be used as a design standard for calorific value of feces. All studies were carried out in North America and Europe therefore no correlation could be made between income and calorific value. However, the largest quantities of fecal energy are shown from diets containing a large amount of unavailable carbohydrates (Southgate and Durnin, 1970), defined as all polysaccharides not hydrolyzed by the intestinal secretions of humans, as opposed to available carbohydrates such as starch and sugars which result in less fecal energy loss (Southgate, 1973).

3.2.6 Fiber

Human stools contain approximately 25% undigested plant matter, not including any nitrogenous material (Volk and Rummel, 1987). Fiber is present in stools due to the large linked polysaccharides that inhibit digestibility (Volk

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and Rummel, 1987), therefore the dietary intake will strongly influence the quantity found in feces. The quantity of fiber found in feces (n = 8) ranged from 0.5 to 24.8 g/cap/day with a median value of 6 g/cap/day (Figure 4). Fiber consumption has also been shown to have significant effects on other variables. It was found by Beyer and Flynn (1978) that when a high fiber diet was consumed and compared to a low fiber diet then measurements of fecal fat, protein, carbohydrate, and calories were more than doubled. Similar conclusions were made by Kelsay et al. (1978) when a high fiber diet from fruit was consumed. It was concluded that this was down to fiber consumption having a significant impact on absorption capacity in the gut.

3.3 Inorganic Composition

The remaining solids compose the inorganic fraction which is predominantly made up of calcium phosphate and iron phosphate, intestinal secretions, small amounts of dried constituents of digestive juices such as shredded epithelial cells and mucus (Guyton and Hall, 2000; Iyengar et al., 1991). Fixed solids were measured at 3.13 g/cap/day by (Cummings et al., 1996) which was 2.25% of fecal wet weight and 9.02% of fecal dry weight. Fixed solids are in the range of 7.5–16% of TS s (Feachem et al., 1978; Nwaneri et al., 2008; Bai and Wang, 2011); using the assumption of 29 g/cap/day TS then this would give a fixed solid value of between 2 and 4 g/cap/day.

In a healthy fully grown adult the amount of inorganic elements are in equilibrium (Kujawa-Roeleveld and Zeeman, 2006) and are not subject to any transformation within the body (Muñoz et al., 2007). Therefore it would be expected that the intake of elements would be equal to the output in human excreta. The intake of nutrients is therefore of great importance as well as the partitioning of these elements between the two excreta streams of feces and urine. Wignarajah et al. (2003) found that the partitioning of elements between the urine and fecal fractions could be determined by looking at% absorption rates of inorganic elements in the body. Absorption rates were found to be predictable and reliable, therefore if the elemental input of the diet is known for an individual or population (alternatively it could be predicted from recommended daily allowance figures for that population), the partitioning between urine and fecal fractions could be predicted. This is because elements that are absorbed by the body will be excreted in the urine fraction and the remaining fraction will be voided in the feces.

However, absorption rates are not clearly defined at high intake rates; an example cited by Wignarajah et al. (2003) is the partitioning of phosphate. The phosphate absorption rate at normal intake levels is 60%, however, at high rates of phosphate intake the absorption rate is markedly reduced to 40%. This means that at high levels of phosphate intake the relative amount

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of phosphate voided in feces can be increased from 40% to 60% as the amount absorbed and excreted in urine is reduced.

Minimum and maximum values of elements (Table 5) can be used as an estimate of daily loading rates of elements voided in feces; the variation is likely to be due to the differing dietary intakes which were not recorded. The intake of elements is therefore the most important variable. Therefore, factors that have an effect on this, such as heavy metal contamination of farmland or high concentrations of certain elements, such as lead in the air as a result of industrial pollution, also bear importance. Increased fiber intake has also been shown to lead to an increase in inorganic constituents, particularly Na and P (Southgate et al., 1976). Feachem et al. (1978) recorded% concentration of P, K, and Ca at 3–5.4%, 1–2.5%, and 4.5% respectively in the dried solid fraction. Levels of P in feces have been shown to increase with increasing protein intake; however, protein intake had no other impact on Mg, K, and Ca (Calloway and Margen, 1971). The total quantity of feces voided will also have an impact on the quantity of constituents; Na, K, Mg, Ca, and Zn were all found to be strongly correlated with fecal wet mass (Eastwood et al., 1984).

3.4 Chemical Nature

Fecal pH is neutral with a median value of pH 6.6 and a range of mean pH values of 5.3–7.5 (n = 28) (Figure 5). Fecal pH not only varies between different populations but has also been proven to differ between individuals consuming the same diet and with time (Silvester et al., 1997). Van Dokkum et al. (1983) found a difference of 0.25 in the fecal pH between sampling

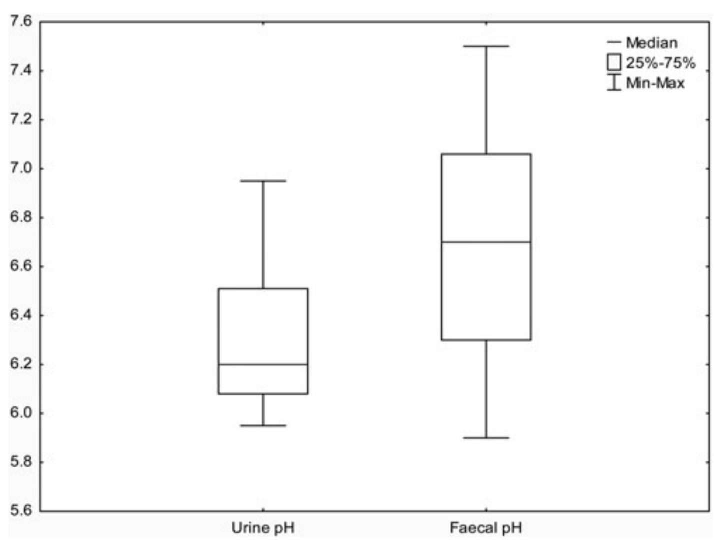

FIGURE 5. Mean pH values for urine (n = 9) and feces (n = 23).

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separated by two days in the same individual when exactly the same diet was consumed.

Fecal pH variation is related to diet (Thornton, 1981; Van Dokkum et al., 1983). Increased dietary fiber was suggested by Newmark and Lupton (1990) to lower fecal pH. However, not all studies have found that high fiber diets correlate with lower fecal pH. In a comparison study of omnivorous and vegetarian diets by Walker and Walker (1992), no significant difference in pH values for the stool or stool water were observed, even though the vegetarian diet provided considerably more fiber. Similarly in a comparative study of omnivorous and vegetarian diets by Van Faassen et al. (1993) no difference between pH values for the stool or the stool water were observed, even though the vegetarian diet again, provided considerably more fiber.

High levels of RS in diets was also shown by Phillips et al. (1995) to lower fecal pH in a controlled experiment of differing RS intakes, a significant inverse relationship between RS intake and fecal pH was found ($r = -0.65$, $p < .01$). Interestingly 30% of the variance of fecal pH in a study by Van Dokkum et al. (1983) was accounted for by calcium intake, showing a significant positive correlation. Evidence of variation in fecal pH is not conclusive and variation could be due to a specific dietary intake, such as citrus fruit which has been proven to lower fecal pH (Walker et al., 1979).

3.5 Physical Form

For the development of onsite treatment technologies an understanding of the physical form of feces is important; this characterization can be done through the use of visual scales or prevalence rates of diarrhea and constipation.

3.5.1 Visual Scale

Within the medical literature a number of linear scales have been used to characterize feces e.g., Davies et al. (1986), however, with different scales in use cross comparison of studies is difficult. The most popular scale used is that of Lewis and Heaton (1997) who proposed the "Bristol Scale Stool Form" (Figure 6). This simplified visual scale provides an indication of the form of feces expected and the variation that can be observed across a population. Stool form is considered abnormal when type 1, 6, and 7 occurs and this is 15% of the time within a healthy population (Heaton et al., 1992). The mean value for a general population sample of 66 people using the Bristol Stool Form scale have been placed at 3.6 by Lewis and Heaton (1997). The distribution of the physical form in two populations of differing countries shows that stool types 3 and 4 are most commonly reported (Figure 6). Variation occurs between individuals, by age and gender (Heaton et al., 1992), although diet and health prove more important variables (Davies

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et al., 1986; Heaton et al., 1992). Dietary fiber is linked to stool texture, as dietary fiber increases stools become softer (Davies et al., 1986).

3.5.2 Diarrhea

Diarrhea has an impact on stool production, structure, form, and composition.

In a controlled study by Wierdsma et al. (2011) it was found that patients in an intensive care unit with diarrhea had over five times the wet fecal weight (796 g/cap/day versus 157 g/cap/day) compared to those without diarrhea. Increased water losses are the predominant cause of the increase in weight; an increase in water content of 5% was shown by Wierdsma et al. (2011) and in a study by Goy et al. (1976) feces of patients with diarrhea had a significantly ($p < .05$) greater percentage water content compared to control subjects. fecal water loss of more than 10 mL/kg body weight is often used as a definition of chronic diarrhea (Auth et al., 2012). Those with diarrhea display higher fecal protein losses of 16.2 g/cap/day versus 5.6 g/cap/day and higher fecal energy losses were also shown in comparison to patients with normal stools (Wierdsma et al., 2011). However, fecal energetic content per gram of feces (kcal/g wet feces) was not significantly different between subjects with and without diarrhea (Wierdsma et al., 2011).

Diarrhea is defined as a minimum of 3 liquid stools per day; it is further sub-divided into acute diarrhea (defined as diarrhea lasting up to 3 weeks) and chronic diarrhea (lasting any longer than 3 weeks) (Patel and Thillainayagam, 2009). It has been classified as stool types 6 and 7 on the Bristol Stool Form Scale (Figure 6). Chronic diarrhea prevalence rates in five studies across the UK, US, and Asia show an average of 4.6% (Table 7) with prevalence more frequent in the elderly at rates of 14.2% (Talley et al., 1992). Acute (infectious) diarrhea is caused most commonly by viruses, bacteria, and protozoa and is commonly transmitted by the fecal-oral route through water, food, and person to person contact (Farthing and Kelly, 2007). Acute diarrhea prevalence figures have been applied to geographic areas, such as in the United States where there is an equivalent of 1.4 episodes per person

TABLE 7. Diarrhea prevalence in a selection of six countries

Study	Country	n	Chronic diarrhea prevalence (%)
Han et al. (2006)	Korea	1066	6.6
Chen et al. (2000)	Singapore	271	7
Danivat et al. (1988)	Thailand	1077	2.3
Danivat et al. (1988)	UK	301	4.7
Sandler and Drossman (1987)	UK	1128	3.6
Danivat et al. (1988)	USA	789	4.9
Tan et al. (2003)	Malaysia	84	3
Average across studies		7	4.6

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TABLE 8. Per Capita Generation of Components in Urine

Variable	Range (median) (g/cap/day)	References
Total N (n = 8)	2–35 (11)	
Urea	10.00–35.00	Bender and Bender (1997)
	1.36–6.77	Calloway and Margen (1971)
Ammonia	0.34–1.2	Bender and Bender (1997)
Creatine	0–0.15	Dong (1999)
	<0.10	Bender and Bender (1997)
Creatinine	0.001–0.002	Bender and Bender (1997)
	1.640	Dong (1999)
	1–1.800	Harper et al. (1977)
Uric acid	0.25–0.75	Bender and Bender (1997)
	0.86	Dong (1999)
	0.50–0.80	Harper et al. (1977)
Total P	0.93	Jönsson et al. (2005)
	0.62–0.74	Taylor and Curhan (2006)
	0.45–0.71	Borawski et al. (2008)
	1.15–1.30	Calloway and Margen (1971)
Total K	0.78–2.50	Wignarajah et al. (2003)
	2.5	Del Porto and Steinfeld (1999)
	0.027–0.036	Borawski et al. (2008)
	2.51–2.87	Calloway and Margen (1971)
Na	3.45–4.53	Wignarajah et al. (2003)
	0.082–0.163	Borawski et al. (2008)
SO_2-4	1.34–1.63	Taylor and Curhan (2006)
Ca	0.20–0.50	Wignarajah et al. (2003)
	0.118–0.113	Taylor and Curhan (2006)
	0.057–0.134	Borawski et al. (2008)
	0.14–0.25	Calloway and Margen (1971)
Mg	0.19–0.21	Calloway and Margen (1971)

per year (Herikstad et al., 2002) and in the UK with just under 1 episode per person per year (Feldman and Banatvala, 1994).

Acute diarrhea prevalence is higher in low income countries as many of the risk factors of contracting diarrheal illness are associated with poor socioeconomic conditions (Ahs et al., 2010). Factors that increase exposure to infectious diarrhea include lack of access to safe water supplies, inadequate sanitation facilities, and poor personal hygiene. Added to this factors that reduce resistance to infection are also important such as age, malnutrition, and illnesses such as the human immuno-deficiency virus (HIV) (Ahs et al., 2010). Geographically, there is an overlap of areas with a large burden of diarrheal illness and those with a large proportion of HIV cases; some enteric pathogens have also been shown to occur more frequently in HIV-positive individuals than in the general population, including campylobacter, cryptosporidium, and shigella (Ahs et al., 2010). Zinc and vitamin A deficiencies have also been shown to increase susceptibility to diarrhea episodes, especially in children (Walker and Black, 2004).

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Diarrhea disproportionately affects children in low and middle income countries due to inadequate water and sanitation facilities and nutritional risk factors (Fischer Walker et al., 2012). In a systematic review by Fischer Walker et al. (2012) diarrhea prevalence rates in children were estimated at 2.9 episodes/child year, with incidence rates the highest among infants aged 6–11 months. In an overview report by the World Bank, data collected by a Demographic and Health Survey (DHS) project between 1990 and 2005 was presented by Gwatkin et al. (2007) with prevalence measured according to the% of children under 5 who had diarrhea in the 2 weeks prior to the survey; population averages for the regions of South Asia (15.3%), Sub-Saharan Africa (19.7%), East Asia, and the Pacific (13%) were recorded (Gwatkin et al., 2007). Infectious diarrhea is also more common among elderly populations due to increased incidence of immunodeficiency and resultantly an increased likelihood of bacteria in the blood (DuPont, 1997).

Seasonality affects the prevalence rates of diarrhea. It has been observed that acute diarrhea becomes an epidemic in the rainy season in places such as Kathmandu (Karki and Tiwari, 2007) this is largely due to the problem of water supply contamination. However, in a cross-sectional study of diarrhea in children under 5, a negative association between rainfall and diarrhea rates was found by Lloyd et al. (2007) with a 4% increase in diarrhea incidence (95% confidence interval, CI: 1–7%, $p = .02$) for each 10 mm month^{-1} decrease in rainfall, this was thought to be due to the use of unprotected water sources during water scarcity.

3.5.3 Constipation

Constipation has prevalence rates that can range from 1.9% to 27.2% in an American population (Higgins and Johanson, 2004); however, it is commonly found at 6–12% in a general population (Heaton et al., 1992; Talley et al., 1993; Thompson et al., 2000). Constipation increases with increasing age, particularly after the age of 65 (Higgins and Johanson, 2004). Only one comparative study (Aichbichler et al., 1998) of fecal characteristics of constipated and non-constipated subjects was found; concluding that stool weight per week was markedly reduced in constipated subjects due to a reduction in stool water and TS output. There are numerous other studies that report fecal weights of constipated subjects, e.g., (Ashraf et al., 1996; Chen et al., 2008) these studies report daily per capita weights that fall within the study range presented (for example, in a study of constipated subjects by Chen et al. (2008) values of 108.3 g/cap/day were recorded, in comparison to the median value of 128 g/cap/day reported in this study); however, shorter experimental studies can often be misleading and it is often the case that over prolonged study periods of weeks or even months stool weights can be considerably decreased (Aichbichler et al., 1998).

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3.6 Urine

In contrast to feces, the characteristics of urine have been studied extensively (Diem and Lentner, 1970; Kirchmann and Pettersson, 1994; Karak and Bhattacharyya, 2011). Urine as a potential fertilizer has attracted much attention in the treatability sector with a large range of literature exploring the agricultural fertilizer potential (Palmquist and Jönsson, 2004; Karak and Bhattacharyya, 2011; AdeOluwa and Cofie, 2012). Urine presents less danger to human health in comparison to feces and contains few enteric microorganisms, however, some human pathogen microorganisms such as *Schistosoma haematobium*, *Salmonella typhi*, *Salmonella paratyphi*, and *Leptospira interrogans* as well as helminth eggs can be found in the urine fraction (Feachem et al., 1978; Heinonen-Tanski and van Wijk-Sijbesma, 2005).

3.6.1 Liquid Generation

Human urine is a liquid that is secreted by the kidneys, collected within the bladder and excreted through the urethra. Urine is composed of 91–96% water (Drangert, 1998; Höglund et al., 2000; Heinonen-Tanski et al., 2007) and the remainder can be broadly characterized into inorganic salts, urea, organic compounds, and organic ammonium salts (Putnam, 1971).

Liquid generation from humans is dependent on the water balance of individuals. Liquid output is in the form of urine, fecal water, from the skin through sweating, and from the lungs through respiration. A median volume of 1.4 L/cap/day urine is excreted with mean values ranging from 0.6 to 2.6 L/cap/day ($n = 14$). In medicine, urine output is used to assess circulatory adequacy with inadequate urine output considered at <0.5 mL/kg body weight/hour for adults (Suen et al., 1998) and at 1–1.5 mL/kg body weight/hour in children (Yowler and Fratianne, 2000). This indicates the minimal urine output that can be expected.

Variation in total urine output (Figure 3) is primarily due to fluid intake and in a study by Parker and Gallagher (1992) accounted for 78% of the variation observed in a sample of 11,748 days' worth of data. It was noted by Garrow et al. (1993) that the volume of water drunk as fluid is generally equal to the volume of urine produced. Body size is inevitably important when assessing a human's urinary output; when assigning loading rates in wastewater, Almeida et al. (1999) reduced urinary output by 33% for children such that Karak and Bhattacharyya (2011) stated that children urinate about half that of the volume excreted by adults. Urine output therefore increases with body size. Other factors leading to variation such as excessive exercising or sweating will have an effect on the quantity of urine generated as they will impact hydration. Variation in urine output according to race has been proven significant with the urine volume of black women 0.24 L/day less than white women ($p = .001$) (Taylor and Curhan, 2007). It was also observed by

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Clark et al. (2011) that higher volumes of urine tended to be from subjects who were older, were more likely to be obese or taking medication.

Information regarding the number of times urination takes place over a 24 hr period is sparse and is likely to vary greatly due to fluid intake, biological factors, and health of the individual. Schouw et al. (2002) recorded a figure of 5.4 urinations per day in a boy's prison in Thailand and Bael et al. (2007) reported a median figure of 6 urinations/24 hr (range of 2–11 urinations/24 hr) in a study of children aged 6–12 years. A figure of 8 urinations per 24 hr period was recorded for a population sample in the United States (n = 17) (Clare et al., 2009). The diurnal variation of urinary output is not commonly recorded, however, a control sample of 15 healthy adult subjects showed that 60% of total urine volume was excreted during the daytime (09:00–21:00) and 40% was excreted at night time (21:00–09:00) (Hineno et al., 1994).

3.6.2 Composition

Urine composition varies due to differences in physical exercise, environmental conditions, as well as water, salt, and high protein intakes. Urine osmolarity is a measure of the water distribution amongst fluid components. It can vary between 50 and 1200 mOsmol/kg, with the average urinary excretion of solute 1000 mOsmol/cap/day (Garrow et al., 1993; Callis et al., 1999). This solute is excreted in a median volume of 1.4 L/cap/day of urine. The quantity of solute varies between individuals and with differing diets; for example, the high consumption of meat leads to larger volumes of solutes as meat is a major source of urea (the largest solute fraction) as well as potassium and phosphates, whereas vegetarian diets are likely to lead to reduced solute production as most energy is derived from carbohydrate (Garrow et al., 1993).

The median value of mean total urine solids loading rates is 59 g/cap/day (n = 7) and mean values range from 57 to 64 g/cap/day. The dry matter of urine was measured at 4.7–10.4 g/L by Heinonen-Tanski and van Wijk-Sijbesma (2005). The concentration of total suspended solids has been recorded at 21 mg/L (Almeida et al., 1999) and total dissolved solids have been recorded at 31.4 mg/g (Putnam, 1971). Organic matter makes up between 65% and 85% of urine dry solids (Strauss, 1985), with volatile solids comprising 75–85% of TS (Fry and Merrill, 1973; House, 1981). Urea is the most predominant constituent making up over 50% of total organic solids, and is produced through the metabolism of protein. The other major solutes excreted in urine are Na and K, which are largely derived from dietary intake.

3.6.3 Chemical Composition

Dry urine solids are composed of 14–18% N, 13% C, 3.7% P, and 3.7% K (Strauss, 1985). Concentrations of major elements in urine were recorded at 6.87 g/L carbon, 8.12 g/L nitrogen, 8.25 g/L oxygen, and 1.51 g/L hydrogen

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by Putnam (1971). Of the feces and urine fractions, urine contains the largest proportion of N (90%), P (50–65%), and K (50–80%) released from the body (Heinonen-Tanski and van Wijk-Sijbesma, 2005).

Nitrogen is predominantly in the form of organic nitrogen and mostly in the form of urea (Beler-Baykal et al., 2011). Median values of total N excretion of 11 g/cap/day were recorded (n = 8) with a range of mean values from 2 to 35 g/cap/day. Endogenous total N excretion of 13 men with the absence of protein in the diet was 2.41 g/cap/day, with no correlation with body weight found (r = 0.450) (Calloway and Margen, 1971). This therefore provides a minimum figure for N excretion. The dietary intake of protein is the most predominant factor effecting N excretion. Urinary N components increase with increasing levels of protein in the diet; a positive correlation (r^2) between urinary N and protein intake (intake ranging from 51 to 212 g/day) was found to be 0.91 (Magee et al., 2004). In a meta-analysis of data by Kipnis et al. (2001) it was found that urinary N is 80% of dietary intake on average.

Of the nitrogenous fractions urea is the most predominant, making up between 75% and 90% (Lentner, 1981). Urea concentrations range from 9.3 to 23.3 g/L (Putnam, 1971; Otterpohl et al., 2002; Jönsson, 2005), with daily loadings of 1.4–35.0 g/cap/day (Calloway and Margen, 1971; Bender and Bender, 1997). Creatinine is a significant nitrogenous fraction in urine. Endogenous creatinine was measured at 1.59 g/cap/day and was correlated with body weight (22 ± 4 mg/kg, r = 0.918) and is also dependent on age and muscle mass (Calloway and Margen, 1971). Concentrations can vary according to gender with male subjects recording higher ($p = .001$) creatinine values than female subjects, 1.9 and 1.4 respectively (Newman et al., 2000). Concentrations of creatinine in urine also decreases when increasing volumes of urine are excreted over a 24 hr period ($R^2 = 0.618$, $r = 0.786$, $p < .001$) (Newman et al., 2000). If there has been incomplete sampling over 24 hr an internal standard against the creatinine value can be used, with standards of creatinine excretion set at 1.7 g/day in men and 1.0 g/day in women (Jackson, 1966). Nitrate concentrations in urine are low, with measured values at 1.07 mmol/L and 2.06 mmol/day when a high protein diet is consumed (192 g/day) and 1.09 mmol/L and 2.23 mmol/day when a lower protein diet is consumed (68 g/day) (Silvester et al., 1997).

Protein intake is the predominant cause for variation in nitrogen concentrations of urine. In addition to this, protein intake has also been shown to impact other mineral constituents in urine. For example, in very low protein diets P and K were shown to be increased, Ca was reduced in very low protein diets but protein intake had no effect on Mg concentrations in urine (Calloway and Margen, 1971).

Differences in chemical composition have been observed according to race by Taylor and Curhan (2007) with black women (n = 146) excreting 65 mg less Ca ($p < .001$), 351 mg less K ($p < .001$), 11 mg less Mg ($p <$

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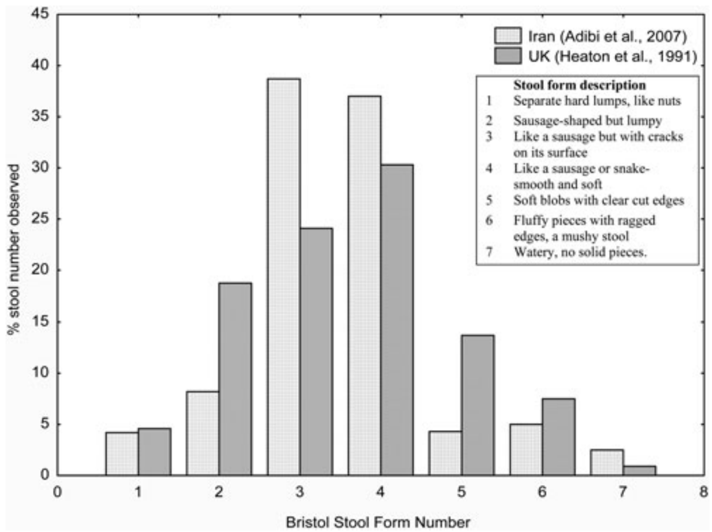

FIGURE 6. Data from two separate studies of healthy subjects (Heaton et al., 1992; Adibi et al., 2007) both use the Bristol Stool Form scale. Stool types 3 and 4 make up the most common stool type in both studies, however all types of stool are recorded in both studies.

.001), and 120 mg less P ($p < .001$) per day than white women (n = 330); these observations were consistent even after adjustment for age and body mass index (BMI). Animal protein in the diet has been shown to lead to increased levels of urinary calcium, with calcium excretion at 21% of intake whereas with higher levels of vegetable protein calcium excretion is 16% of intake (Taylor and Curhan, 2007). Positive associations were found between BMI and urinary calcium excretion, however, it was concluded that this was due to differences in animal protein and sodium intake (Taylor and Curhan, 2006).

3.6.4 Chemical Nature

The pH of fresh urine is largely neutral with a median of pH 6.2, with a range of mean pH values of 5.5–7.0 based on a large subject sample size across nine individual studies (Figure 5). There are numerous factors that can lead to changes in urinary pH but diet once again provides a key variable. Urinary pH is reduced by high protein intake through meat and dairy produce as well as through alcohol consumption (Kanbara et al., 2012). However urine is more alkaline with the ingestion of potassium and organic acids which are increased in diets with high consumption of vegetables and fruit. Taylor and Curhan (2007) found that black women had a higher urinary pH than white women by 0.11 units ($p = .03$) even when adjusted for differences in diet, BMI, and age. Further, an inverse relationship between BMI and urine pH ($p = .02$) was found by Taylor and Curhan (2006). Factors leading to a lower urinary pH include a higher weight, old age, and increased dietary

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acid intake (Hesse et al., 1986; Maalouf et al., 2004; Taylor and Curhan, 2007).

The specific gravity of urine ranged from 1.002 to 1.037 in spot samples of 534 subjects (aged 18–68) with a high correlation (r = 0.82, $p < .001$) observed between creatinine and specific gravity (Carrieri et al., 2000). The COD levels of 8–17 g/L found in urine are low (Table 9); this is likely to be because most of the organics excreted are small molecules. The mean calorific content of urine was measured at 100 kcal/day (range: 91–117) by Southgate and Durnin (1970): using the median value of urine solids produced daily (59.0 g/cap/day) a design value of 1707 kcal/kg can be used.

3.7 Additional Influences on Treatment Systems

Both fecal solids (29 g/cap/day) and urine solids (58–64 g/cap/day) are produced daily in large quantities. A mixed stream treatment system at source will therefore have to deal with a large quantity of solids from both feces and urine. However, it is also the case that feces and urine are likely not to be the only additions to a treatment system. A treatment system may also have to deal with additional material from human behavioral practices such as the use of toilet paper or the addition of sanitary items (Table 10). A similar principle applies to water addition; a large liquid fraction is produced daily through urine and fecal output; however this may be further increased by additional water inputs such as pour flush toilet systems or anal cleansing practices.

4. DISCUSSION

Existing OSS facilities are often poorly designed, constructed, and maintained which regularly results in inadequate sanitation facilities in many low income regions. This problem has given rise to research into the on-site treatment and/or resource recovery from feces and urine within a low income context. This trend has accelerated with the challenge presented to researchers by the Bill and Melinda Gates foundation to "Reinvent the Toilet" (Global Development Program, 2013). A large proportion of this research aims to treat feces and urine as a fresh waste stream on the site of production, giving a need to understand the production, composition, and any variation around these factors in order to determine how this may impact these technologies. In this discussion all types of conventional treatment processes were considered alongside recent research funded by the Bill and Melinda Gates Foundation (BMGF). These grants (Sustainable Sanitation Alliance, 2013) were grouped according to their treatment pathways comprising; biological processes (17), physical separators (7), chemical processes (3), and thermal

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TABLE 9. Concentration of key components in fresh urine

Variable	Concentration range (mg/L)	References
Electrical conductivity EC	160 mS/cm	Jana et al. (2012)
	270 mS/cm	Jönsson et al. (1997)
Osmolarity	1025 mosmol/kg	Callis et al. (1999)
	50–1200 mosmol/kg	Garrow et al. (1993)
COD	17,500	Putnam (1971), Almeida et al. (1999)
	6270–10,600	Putnam (1971)
Total N	8000	Ban and Dave (2004)
	5000	Jönsson et al. (2004)
	11,000–13,900	Jönsson et al. (2004), Southgate and Durnin (1970)
	4000	Jönsson et al. (1997)
	12,000	Mojtahedi et al. (2002)
	11,700	Beler-Baykal et al. (2004)
TKN	9220	Beler-Baykal et al. (2011)
	5580–7900	Putnam (1971)
Urea	21,400	Jönsson (2005)
	9300–23,300	Putnam (1971)
	10,000	Otterpohl et al. (2002)
NH_4-N	125	Jana et al. (2012)
	600	Beler-Baykal et al. (2004)
NH_3-N	480	Tilley et al. (2008b), Diem and Lentner (1970)
	200–730	Putnam (1971)
	300	Tilley et al. (2008a)
Total P	350	Jönsson et al. (1997)
	800–2500	Wignarajah et al. (2003)
	1000	Del Porto and Steinfeld (1999)
	1800	Ban and Dave (2004)
PO_4-P	205	Tilley et al. (2008a), Diem and Lentner (1970), Jana et al. (2012)
	450	Tilley et al. (2008a)
	760	Diem and Lentner (1970)
K	966–1446	Beler-Baykal et al. (2004)
	1200	Jönsson et al. (1997)
	750–2610	Putnam (1971)
Ca	230	Diem and Lentner (1970)
	32	Jana et al. (2012)
	70	Tilley et al. (2008a)
Mg	120	Diem and Lentner (1970)
	70	Tilley et al. (2008a)
Creatine	0–890	Putnam (1971)
Creatinine	311–2150	Putnam (1971)
Uric acid	40	Putnam (1971)
	152–858	Jen et al. (2002)
	856	Dong (1999)

processes (8). The principle aim of this discussion is to understand how the production rates, physical and chemical composition of feces and urine can lead to an improved understanding of potential treatment pathways that

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TABLE 10. Components and generation rate of human excreta waste streams and possible additional inputs

Component of solids fraction	Generation rate (g/cap/day)	Component of liquid fraction (L/cap/day)	Generation rate
Stool mean (range) g/cap/day	32 (4–102)	Stool water mean (range)	0.101 (0.053–0.265)
Urine	61 (50–75)	Urine median (range)	1.42 (0.8–2.45)
Toilet paper use average	11.68–19.4[bc]	Anal cleansing L/wash	0.35–3[de]
Toilet paper use men	6–10.3[abc]	Pour flush toilet water L/flush	1–3[f]
Toilet paper use women	17.9–36[abc]		
Menstrual pads and flow	34[a]		
Sanitary Items. refuse item/cap/day	0.16[b]		

[a]Parker and Gallagher (1992), [b]Friedler et al. (1996), [c]Almeida et al. (1999), [d]Strauss (1985), [e]Tilley et al. (2008b), [f]Cairncross and Feachem (1993).

are either currently in use or under development in the OSS technology sector.

4.1 Biological Processes

The predominant factors likely to impact biological processes to the greatest extent are solids loading, energy content, protein, and fat concentration in the feces and the high urea concentrations in urine.

The high solids loading rate associated with fresh feces (~25% wt.) when viewed as an individual waste stream presents a potential barrier to the successful implementation of high rate anaerobic systems in relation to their solids handling and rheological impacts on mixing and pumping

TABLE 11. Classifications of broad treatment pathways in wastewater treatment

Process type	Examples	Resource recovery
Biological	Anaerobic digestion	Biogas
	Decoupled HRT and SRT	Digestate/Biosolids/liquid fraction
	UASB	Biofuel production
	Wet and dry composting	Compost fertilizer
Thermal processes	Pyrolysis/gasification	Energy/Char
	Incineration	Energy/Ash
Separation	Biofiltration	Pathogen free water
	Membrane pervaporation	Pyrolysis
Chemical processes	Electrochemical disinfection	Pathogen free products
	Ammonia disinfection	NPK irrigation water/fertilizer
	Struvite	Phosphorus
	Ammonia stripping	Fertilizer

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(Speece, 2008). Accordingly, high solids anaerobic digestion processes (operating with solids concentrations greater than 15% w/w) represent a more appropriate match due to the significantly lower impact associated with mixing. Operation at the higher solids loadings will translate to smaller reactor volumes, lower energy requirements, and less material handling than traditionally encountered with standard anaerobic digestion (Guendouz et al., 2008) but would most likely result in a reduced rate and lower biogas yields. For biological processes such as aerobic composting the optimum moisture content is 30–60% (Liang et al., 2003): the moisture content of feces was greater than this (75%) increasing the potential for anaerobic conditions to develop due to water logging (Tiquia et al., 1996). Therefore, incorporation of dewatering pretreatment or a cocomposting feedstock should be considered in order to establish resilient conditions to maximize the efficacy of the desired aerobic degradation pathways. Importantly, the fluctuating levels of moisture content reported in feces (63–86%) means that amendment strategies need to be appropriately flexible and robust and are likely to require a degree of bespoke commissioning.

Based on the COD values collected in this study each 66 g/cap/day COD added and removed by a digester could theoretically produce 0.0175 m^3 of methane at standard temperatures and pressures (Grady et al., 1999). Practical delivery of such potential is dependent on anaerobic reactor type, retention time, and biodegradability such that actual conversion of the available organic matter to biogas is expected to range between 40% and 90% (Mang and Li, 2010). For instance, a key variable is associated with the fiber content of feces which was found to vary widely (Figure 4); especially in populations consuming high fiber diets (such as diets consumed in low income countries). The importance of this relates to the relatively lower biodegradation rate of the fibrous material resulting in reduced COD conversions. Importantly, increased wet mass production rates above the average (128 g/cap/day) are commonly associated with increased levels of indigestible fiber in the feces. Accordingly there is a poor correlation between wet mass loading and energy production. Whilst this places a risk of overestimation during design for such systems the impact can be readily accounted for as the fiber content of feces is directly dependent on the non-degradable fiber intake of the population within the associated catchment. Consequently, the fiber composition of feces for a given population can be predicted if diet is known and accounted for in such calculations.

Potential biogas production from feces could therefore be significant, however, the relatively small quantities of solids produced per cap/day should be noted and may mean that in order for significant quantities of methane to be produced a large population would be required or an additional codigestion feedstock. This factor is likely to be problematic to small

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household or community anaerobic digester designs that cite methane production as a key driver for gaining energy neutral systems or for additional cost recovery.

The efficacy of biological processes for the treatment of feces and urine, in either aerobic or anaerobic processes, may be inhibited through imbalances in the macronutrient composition of such streams. For instance, anaerobic digestion proceeds optimally when the C:N ratio is around 20:1 to 30:1 (Parkin and Owen, 1986); this is not the case in feces (8:1), urine (0.8:1) or as a combined waste stream (2.3:1). Similarly, in aerobic systems the recommended ratio for C:N:P (100:10:1 to 100:5:1) (Tchobanoglous et al., 2003) would not be reached. However, imbalances in the macronutrient composition could be rectified through the use of organic waste substrates that are frequently locally available and could be a simple means of increasing the viability of biological systems.

Potential chronic toxicity for treatment by anaerobic processes can be assessed according to the moderately inhibitory and strongly inhibitory concentration classifications according to Parkin and Owen (1986). Feces as a single waste stream showed concentrations of Na^+, K^+, Ca^{2+}, and Mg^{2+} that were of moderately inhibitory concentrations with values of K^+ reaching levels defined as strongly inhibitory on occasions. Toxic metals such as Cu, Ni, Cr, and Pb were not of significant concentrations to inhibit anaerobic processes of a feces waste stream. However, the high concentrations of sulfide reported have the potential to exhibit toxicity to methanogenic bacteria (Speece, 2008); this will only occur when high levels of sulfate are entering digesters along with sulfate reducing bacteria. Relatively high levels of sulfate 1.34–1.63 g/cap/day were recorded in urine but with very small amounts of elemental sulfur found (0.16 g/cap/day) in the feces fraction.

Nitrogen excreted in urine and voided in feces was shown to vary according to diet (primarily levels of protein intake) and combined median daily losses (13 g/cap/day) could have the potential to lead to ammonia toxicity problems. Ammonia (NH_3-N) concentration is a function of ammonium (NH_4^+) concentration, temperature and pH (Speece, 1996); thresholds in anaerobic systems can be found at concentrations of 100–500 mg/L depending on adjustment time (Tchobanoglous, 2003). Measurements of ammonia in feces are within this range (204–409 mg/kg), although a significant proportion of protein (29 g/kg) was found in the feces fraction that will degrade to produce additional ammonia, dependent on storage time and conditions. The addition of urine to this waste stream (urine comprises 80% of total N losses) could lead to ammonia threshold limits being exceeded in an undiluted waste stream. This is because a large proportion (>80%) of the nitrogenous fraction of urine is in the form of urea, which in turn breaks down into ammonia. Therefore, ammonia toxicity (resulting from urea toxicity) is likely to be problematic when feces and urine are treated as a combined waste stream and significant dilution could be necessary. Toxicity from the urine

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fraction could have negative impacts on biological systems as relatively large volumes of urine are collected in relation to feces (daily urine:feces ratio on a weight basis of 11:1). Accordingly it is suggested that smaller household systems that treat a combined feces and urine waste stream need to especially consider such issues and may be enhanced through inclusion of source separation. Source separation could be carried out through the use of urine diverting toilets in which the feces and urine fractions are collected separately within the toilet bowl.

4.2 Physical Separators

There are numerous different types of separating technologies; however, the majority are likely to be predominantly influenced by variation in the solids content, physical form, as well as levels of protein and fat in feces.

For technologies based on separation the lack of a standard feces shape, structure, and water content may be one of the greatest challenges. This could impact bound water removal from different stool types and also the different particle sizes that make up feces. This uncertainty could be problematic when selecting process types and optimization operating conditions. In addition to this feces show a low proportion of fixed to volatile solids which could make dewatering challenging and require the addition of increasing amounts of chemicals or conditioning agents in order to gain adequate separation without pretreatment.

Significant levels of protein in the feces fraction (29 g/kg) and the potential for fluctuations in this value (range of 19 to 122 g/kg) may be unfavorable to separation processes such as membrane and other surface filter systems. Layers of protein that form on the outside of particles could lead to clogging and its deposition and adhesion to membrane surfaces may cause fouling (Chan and Chen, 2004). Similarly fat can be problematic to separation technologies as it can act as a binder for particles (Nguyen et al., 2012). Fat content in feces shows variation across studies (Figure 4) but remains within a narrow region (5.8 to 49.1 g/kg). The concentration of fat in feces (median of 25 g/kg) is comparatively low in comparison to conventional types of wastewater sludge such as primary sludge which has much higher levels of fats, oils and greases: this is usually due to the discharge of these products in the sewage system. Nevertheless, shock loads due to variation in the fat content of feces may be large enough to cause the clogging of pores and impact dewatering properties.

Information regarding the physical structure immediately after voiding provides an indication as to how the structure of feces may change over short time periods, for example, in the Bristol Stool Form scale a number of 1 or 2 would suggest a feces structure that holds its shape to a much greater extent than others in the scale. Studies were found regarding the settling and thickening of excreta from septage and public toilet tanks (Heinss et al.,

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1999) but in this review no studies were found regarding the change in the physical structure of feces once voided over shorter time scales. This lack of data regarding the change in physical structure over time is limiting current ability to fully understand technology needs. Importantly, the time required to lose the initial consolidated identity of the fresh fecal material is required to understand the potential virtue of utilizing fast separation processes that could benefit from the initial cohesion of the solid material. However, such development must also take into account looser fecal material that will also enter such systems and is likely to be significantly less effectively removed by physical processes. Accordingly, understanding the kinetics of the structural change in fecal material during the initial periods after generation remains a critical area for future research activity that could inform novel low cost technology development.

4.3 Chemical Processes

Chemical treatment processes can be wide ranging and are dependent on the end use and initial purpose of treatment and include processes such as chemical precipitation, disinfection, oxidation, neutralization, and stabilization.

Perhaps the most obvious process relates to precipitation of the available phosphorus, magnesium, calcium, and sulfur along with the other micronutrients that exist within fecal material and urine (Table 9), in particular the use of source separation to enable recovery of the high content of P in urine (0.4–2.5 g/cap/day) through struvite precipitation. The pH of feces and urine are both slightly acidic in nature (Figure 5), however, the pH level is likely to increase over short time periods which helps drive the precipitation reactions. Indeed, this self-induced onset of precipitation can be detrimental to treatment technology through the precipitation of unwanted scale forming crystals and is considered a particular problem in the supernatant following solid/liquid separation. Nevertheless, the nutrient potential of feces should not be underestimated, with 50% of N being water-soluble as well as 40% of total P excretion being voided in the feces.

4.4 Thermal Processes

Efficient thermal technologies have been the focus of much development because of their potential for energy saving and cost recovery. However, although there is great potential for energy production there is the negative aspect of the loss of nutrients present within feces and urine as the majority are made unavailable for agriculture use. The cost efficiency of the process is primarily dependent on the water content of excreta and its calorific value.

The TS content of feces and urine is likely to be the most important factor impacting thermal treatment technology, with TS content of feces (25%)

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and urine (1%). The TS content and its variation will determine the financial viability of thermal processes and whether it can be a viable feedstock. However, the TS content of feces (25% TS), is in a similar range to that of dewatered sludge (typically 22–36% TS) from conventional sewage treatment works using belt-filter press, filter press, and centrifuge dewatering (Tchobanoglous et al., 2003). This is important as it highlights that when feces are voided the material is already at the level of de-watered sludge if it could avoid being diluted. This could therefore mean that thermal treatment technologies could potentially be used without prior dewatering processes and this factor could promote collection practices that involve less dilution of the waste stream highlighting again the need to understand the time related change in fecal identity that occurs during the initial periods after being voided.

Variation in water content (Figure 3) was significant with a range of 63–86%. Diet was the predominant cause for variation in water content (predominantly fiber intake) in healthy subjects, however, in unhealthy subjects this range can further increase due to the prevalence of diarrhea. Chronic and acute diarrhea within populations could have a significant impact on treatment technology as feces of those with diarrhea showed increases in water content and a change in physical structure. Global averages of diarrhea prevalence are significant in developed countries; therefore, this should be accounted for and amplified for technologies aimed at low income regions where both the chronic and acute diarrhea prevalence rates are likely to be significantly greater. In contrast to diarrhea, constipation decreases the water content of feces and is equally prevalent in the developed world. Scales relating to the physical form of feces also provides a further estimation of the solids composition by providing approximate estimations of the TS content of feces across large sectors of populations. Research being carried out by Wooley et al. (2013) into assigning a TS value to the Bristol Stool Form scale will be of further benefit to technology development in this respect. Extremes in solids composition may cancel each other out in an averaging effect; however, thermal systems would have to be capable of dealing with this wide range and potential fluctuations in water content.

The calorific value can be used as a metric of potential energy that can be produced during combustion of excreta. Calorific value of feces (4115 kcal/kg) shows lower values in comparison to animal manure feed-stocks such as swine (4634 kcal/kg), similar values to cattle manure (4211 kcal/kg) but greater than poultry litter (3611 kcal/kg) (Cantrell et al., 2012). Human feces therefore could present an economically viable option for energy creation through combustion. However, humans will consume a much more varied diet then animals, leading to greater deviation from median values than would be seen in manure feedstock. For example, although there is variation in the calorific value of swine manure from different sites (e.g., 4660–7887 kcal/kg (Cao et al., 2010; Xiu et al., 2010) variation within these

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TABLE 12. Summary table of feces and urine characteristics providing on-site sanitation design criteria

Key design criteria	Median value
Feces	
Fecal wet weight (g/cap/day)	128
Fecal dry weight (g/cap/day)	29
Stool frequency (motions/24 hr)	1.1
Total solids (%)	25
VS (% of TS)	89
COD (g/cap/day)	71
Nitrogen (g/cap/day)	1.8
Protein (g/cap/day)	6.3
Lipids (g/cap/day)	4.1
Carbohydrate (g/cap/day)	9
Fiber (g/cap/day)	6
Calorific value (kcal/cap/day)	132
pH	6.6
Urine	
Urine wet weight (L/cap/day)	1.4
Urine dry weight (g/cap/day)	59
Urination frequency (urinations/24 hr)	6
Nitrogen (g/cap/day)	11
Calorific value (kcal/cap/day)	1701
pH	6.2

sites is limited as the animals are kept under the same conditions and are being fed the same diet. In contrast, variation in the energy value of feces is quite substantial (1523–10,875 kcal/kg). This variation is predominantly caused by the varying presence of unavailable carbohydrates in the diet, the larger the quantity of unavailable carbohydrates the higher the energy value of feces voided. This has significance, as in lower income countries foodstuffs may often have more unavailable carbohydrates, therefore, feces of subjects in lower income countries may have fecal energy values higher than the values presented in this study suggest. As a guideline for calorific values fecal dry mass can be used as an estimate for energy losses in feces (reflecting unavailable carbohydrate intake) and energy adsorption by the body is correlated significantly with fecal dry weights (−0.911) (Calloway and Kretsch, 1978).

The high TS concentration of feces gives a good case for the source separation of feces and urine as the addition of urine could add the further problem of dewatering and could resultantly increase costs of thermal treatment processes. Nevertheless a sizeable proportion of urine solids are produced by humans (59 g/cap/day) and the calorific value of urine (1701 kcal/kg) could contribute to energy production if efficient dewatering technologies were available.

Other factors that may be significant for thermal process regard the potential emissions from any thermal treatment process. Levels of sulfur are

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low in feces but slightly higher levels are observed in the urine fraction, this could be significant as sulfur in oxygen starved conditions is reacted in the form H_2S (Kang et al., 2011).

5. CONCLUSIONS

This review aimed to characterize feces and urine and determine the extent and causes of variation seen and its subsequent impact on technologies treating feces and urine as a fresh waste stream. Table 12 provides a summary of the key criteria and values that will assist in not only the operation of existing OSS systems but will help advance research and development into new OSS technologies.

The generation rate of feces and urine shows significant variation across a wide range of studies presenting difficulties assigning standard design values for treatment technology processes. The values presented are based upon a large database of values from studies worldwide. The median generation rate of feces has been calculated at 128 g/cap/day wet mass and 29 g/cap/day dry mass; however, caution should remain when using these central tendency figures as the data sets were highly skewed. The largest factor leading to variability in fecal mass is the indigestible fiber content of dietary intake; this explains the reason why fecal wet mass values were increased by a factor of 2 in low income countries. A urine generation rate of 1.42 L/cap/day was recorded with the water balance of the body highlighted as the main cause of variation in volume.

Variation in the chemical and physical composition of feces and urine was widespread throughout the study; this means that technology developments must be robust and flexible in order to deal with this uncertainty. It can be concluded however that the composition of feces and urine is highly dependent on the dietary intake of subjects. The predominant factor leading to variation in key parameters in feces was the dietary intake of non-degradable fiber which was shown to impact production rate, stool frequency, TS, fat, protein, and the energy value of feces. In the urine fraction, protein intake was one of the key factors leading to variation in urea concentration as well as impacting concentrations of P, K, and Ca in urine.

Biological treatment processes are likely to be effective at treating feces as a waste stream and a large proportion of the feces are likely to digest readily. However, high non-degradable fiber content of feces may reduce digestibility and with a combined waste stream of feces and urine the anaerobic digestion process may be limited with potential problems such as ammonia toxicity. Technologies based on separation will predominantly be impacted by the variation in TS concentration as well as fluctuating levels of protein and fat found within the feces. Chemical processes will be largely

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influenced by variation in the diet consumed by subjects, leading to fluctuations in nitrogen and phosphorus loads which could be influential on pH levels, precipitation, and nutrient recovery. Thermal treatment processes will similarly be most influenced by variation in TS as well as the energy content of these solids, once again the intake of fiber proved most influential in predicting these factors.

The source separation of feces and urine could prove beneficial for biological treatment such as anaerobic digestion where large urea concentrations in the urine stream could prove problematic and cause ammonia toxicity. Similarly, the separation of the two streams could increase the efficiency of the dewatering process and make thermal processes increasingly attractive. In addition to this the largest proportion of nutrients (e.g., N, P, and K) are found within the urine fraction making nutrient recovery from urine more attractive from this more easily accessible stream. It is therefore evident that source separation could be beneficial to many treatment technologies.

This study has illustrated that there is significant variation in both the production values as well as the physicochemical composition of feces and urine. Therefore, there are limitations in using standard design values in the development of treatment technology. Consequently it is important that treatment technology is robust and flexible enough to deal with the variation exposed. It is however possible to make more appropriate decisions about values of production and composition through the assessment of a target population's diet. Through this a range of dietary factors can be assessed in order to make more informed decisions about design values that specifically target individual populations. Additional data, especially information regarding how the structure of feces changes over time, would be of further benefit to technology development but there is nevertheless no shortage of data regarding the production and composition of feces and urine.

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Jennifer Marlow <[redacted]

Kivalina Biochar Reactor: Request for Letter of NonObjection for DOT lease in Kivalina

[redacted]

Dear Ms. Marlow:

The Alaska Department of Environmental Conservation Air Permits Program (APP) has reviewed the information provided by Re-Locate, LLC regarding a proposed pyrolysis reactor, located in the village of Kivalina, which will convert solid human waste into biochar for reuse and/or disposal.

Based on the information provided to APP, the combined annual emissions from both the reactor and the generator used to start the system would not trigger the state's minor permit thresholds in 18 AAC 50.502(c)(1). In addition, the capacity of the reactor is below the cumulative rated capacity threshold of 18 AAC 50.502(b)(4). Therefore, the Kivalina Biochar Reactor does not require a Title I minor air quality permit with the State of Alaska under Article 5 of 18 AAC 50.

APP reviewed the federal requirements for new incineration units under 40 CFR 60 and also contacted EPA for applicability guidance. EPA has not made a determination on permit applicability of the Kivalina Biochar Reactor, therefore APP is unable to make a final determination whether or not the reactor in question is subject to any federal air quality requirements and a Title V operating permit. APP is unable to provide you with a letter of non-objection at this time. We will contact you when we receive a response from the EPA.

Please contact me if you have any questions.

Patrick Dunn

Alaska Department of Environmental Conservation

Division of Air Quality

555 Cordova Street

Anchorage, Alaska 99501

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